Envirothon NB

Study Guide
Forestry

The New Brunswick Envirothon Study Guide for Forestry will assist students and teachers in preparing for the New Brunswick Envirothon program.

Every year, more than 500,000 students, teachers and families across North America take part in the unique learning experience of Envirothon. The program engages high school students in learning more about four main areas of the environment—soils, aquatics, wildlife, and forests. Students learn in the classroom and through interactive workshops aimed at strengthening scientific knowledge of our natural ecosystems and helping develop foundational skills needed to pursue studies and careers in the environmental sciences.

The program supports students in developing:

- A scientific understanding of natural ecosystems (soils, wildlife, forests, aquatics).
- Each year a fifth topic is chosen to highlight an important and current environmental issue.
- Practical experience in resource management practices and technologies.
- The ability to apply scientific knowledge and creativity in developing innovative and sustainable solutions to major environmental challenges.
- Stronger communication, collaboration, and problem solving skills.

1.0 FORESTRY LEARNING OBJECTIVES

Key Point 1—Forestry in New Brunswick
Knowledge of the history of forestry in New Brunswick, land tenures, New Brunswick forestry statistics, legislation and regulations, forest certification, and the duty to consult with Aboriginal Peoples.

Key Point 2—Forestry in Canada
Knowledge of Canadian forestry statistics, land tenures, our changing forest, and sustainability of Canadian forests.

Key Point 3—Tree Physiology and Tree Identification
Know the parts and tissues of a tree, twig, and leaf and be able to explain how a tree grows. Know what dendrochronology is and how it can be used to understand past environmental conditions. Understand the processes of photosynthesis and respiration and be able to identify common tree species without a key and identify specific or unusual trees using a key.

Key Point 4—Forest Ecology
Knowledge of the typical crown classes of trees and of the Forest Regions of Canada, particularly the Acadian Forest Region and the Boreal Forest Region. Understand forest ecology concepts and factors affecting them, including forest succession, shade tolerance, forest soils, forest fires, and the ecosystem services that our forests provide.

Key Point 5—Forest Management
Understand the various silvicultural treatments associated with reforestation, stand improvement, stand regeneration, and harvesting in even-aged and uneven-aged forest management systems and the types of products that our forests provide.

Key Point 6—Forest Measurements
Be able to recognize some basic features on aerial photographs and know how to determine distances and area on aerial photographs. Knowledge of how to use forestry tools and equipment to measure tree age, diameter, and height as well as stand measurements of density, basal area, and stocking. Knowledge of LiDAR technology and how it is used in enhanced forest inventory in New Brunswick.

Key Point 7—Forest Health
Identify the abiotic and biotic factors in a forest ecosystem and understand how these factors affect tree growth and forest development. Consider factors such as climate, insects, microorganisms, and wildlife.

Key Point 8—Climate Change and Canada’s Forests
Knowledge of the impacts of climate change on Canada’s forests.

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2.0 FORESTRY IN NEW BRUNSWICK

2.1 History of forestry in New Brunswick

The profound relationship between New Brunswickers and their forest heritage began many centuries ago. Early aboriginal inhabitants relied on the forest for food, clothing, and shelter. They developed spiritual traditions based on trees and gathered woodland plants for medicine. European settlers used wood to make everything from barrels and furniture to buckets and sewer pipes. Trees were burned as fuelwood, charcoal, and fertilizer production.

Forestry is the largest industry in New Brunswick today. It has been our economic mainstay since the early 1800s. The history of forestry in New Brunswick came of age in the late 17th century and can be broken down into several distinct periods:

2.1.1 Trade in great ship masts and spars (1760–1800)

The first, shortest, and least disruptive phase in the New Brunswick forest industries—the trade in great ship masts and spars for the British Navy— was a product of environmental conditions and the political conflict in the 1770s caused by the American Revolution.

From a production standpoint, mast making was an uncomplicated industry that involved felling trees and floating them to a harbour where they could be loaded for transatlantic shipment. However, the industry was limited by the need for enormous white pine trees that were straight and free of defects. Large masts could exceed 30 meters in length with a diameter of 75 cm at the small end. They required trees that measured 45 meters in height and 2 meters in diameter at the stump. Masts were moved by teams of oxen in winter and usually cut within sight of a body of water that was deep enough to float a 30-meter stick of wood weighing several tons. It was a highly selective industry that was, on the one hand, wasteful and prone to rapid resource depletion. However, it did not impose a significant drain on the forest reserves of the colony.

Mast making reached its peak during the 1790s and 1800s when New Brunswick produced up to 3,000 masts per year, a substantial proportion of the total shipped from the loyal British North American colonies.

2.1.2 Coming of age (1800–1900)

During the nineteenth century, trees were used to build bridges and make railway ties, but the primary purpose was to build houses and clear tracts of land for agriculture. Farmers used wood from trees to make harrows, tool grips and handles, and toys for their children. Fishermen used wood to build boats and make oars and shipping containers. In the home, fir and spruce were used for making pails, basins, salt boxes, and butter churns, while cedar was often used for containers that did not come in contact with food.

The forests were also an important source of added annual income. It was commonplace and indeed expected that men would go work in the lumber camps in October and not return until the following spring.

Figure1. This photo shows loggers working in a camp in winter. This log building was typical of those found in lumber camps. (Photo credit: Provincial archives of New Brunswick)

The disappearance of ice from the rivers and streams in April heralded the end of the tree felling season and the beginning of the log drive. The logs were thrown into the water and, if possible, assembled into timber rafts to be taken to a port or to a shipyard or sawmill.

Figure 2. The log drive consisted in sending the logs floating downriver, sometimes aided by drivers who kept everything moving in the right direction. Driving was hazardous work, given the ever-present risk of toppling into the icy water. (Photo credit: Provincial archives of New Brunswick).

Sawmilling was a much more appropriate industry for facilitating the transition of New Brunswick from a resource frontier to a settled colony. The value added in manufacturing lumber made the cost of transportation across the Atlantic a smaller proportion of the overall cost of production. By mid-century, there were 640 sawmills in the province.

New Brunswick's extensive river system gave loggers easy access to the interior with its rich stands of pine, spruce, and hemlock. Sawmills churned out square-cut timber for domestic and overseas consumption. At mid-century, forest products accounted for more than 80 per cent of the province's total exports. Most of the product was shipped to Britain, but New Brunswick shipbuilders also consumed their share.

From the early 1800s, sailboat construction was a major occupation in many places around New Brunswick. Several other types of boats were also built in the province during that time. They included fishing boats and freighters. Boat building was one of New Brunswick's leading industries in the 19th century.

Figure 3. The photo shows builders at work in the interior of a boat. In the mid-19th century, shipbuilding was going full steam in New Brunswick. Each ship was built to its own specifications, depending on its intended use: hauling large cargos over the seas, speeding across the Atlantic, or carrying passengers. (Photo credit: Provincial archives of New Brunswick)

Yet despite the improved infrastructure and apparently unlimited forest resources, New Brunswick's timber trade began to decrease. After 1880, foreign tariffs, world recessions, competition from Pacific Coast logging, and the demise of wooden shipbuilding took their toll. The province also experienced a growing shortage of large and accessible trees, caused by years of wasteful cutting practices.

2.1.3 Pulp and paper mills

Pulp mills first appeared in New Brunswick in the late 1800s and grew more numerous after 1900. By 1930, the pulp and paper industry surpassed the lumber industry in terms of its economic output. Although several large pulp mills have closed in recent years, their economic output remains greater than wood products and manufacturing combined (which includes sawmills). Products produced from softwood trees in temperate forests, such as those in New Brunswick, have a long fibre length that make it very desirable because it gives strength to the products that are produced.

Pulp and paper mills created large numbers of jobs: first for building the mill and then actual production work, as well as all the logging and transportation jobs. The raw materials sought after were small softwood trees such as balsam fir and spruce. Paper mills played a major role in the 20th-century economy of New Brunswick.

The laws of supply and demand eventually caught up with the pulp and paper industry. The advent of computers, which decreased the need for paper and newsprint, coupled with less expensive pulp from South America produced from fast-growing species, decreased the demand for pulp products from New Brunswick.

Today, the wood used to feed the pulp mills consists mainly of sawmill residues (wood chips and sawdust). Pulp mills are an important part of the supply chain as they provide sawmills with a market for their wood residues.

2.1.4 What does the future hold?

New Brunswick's forest industry faces many challenges in the coming years. Our forests are an incredibly valuable resource that provide economic, social, and cultural benefits. One advantage of forests is that they are a renewable resource that, when managed sustainably, will continue to provide benefits to society.

Society needs forest products. We need lumber to build our homes and wood fibre is used to produce products that we use daily. The Coronavirus pandemic in 2020 illustrated the need for everyday products such as toilet paper and paper towels. More importantly, the use of wood fibre in the production of masks, gowns, swabs, and other products used by health care workers demonstrated the importance of wood products.

Finding new uses for our forest is important and the forest industry in New Brunswick has already started to explore new and innovative uses for our forest products. An excellent example is two hardwood pulp and fibre mills owned by the Aditya Birla Group and located in Nackawic and in Atholville, two forest-dependant communities. The mills produce high content dissolving pulp or specialty cellulose for the manufacturing of natural-based, viscose staple fibre, used to make rayon in the apparel and home textile industry.

Our history has demonstrated that how we use our forest changes over time. To remain competitive and satisfy the needs of society, our forest must continue to provide important forests products such as lumber and pulp and paper. More importantly, the forest must continue to provide ecological and societal functions such as clean water, clean air, and a place for recreation and spiritual fulfilment.

Refer to section 6.9.4 for more examples of innovative uses of wood.

2.2 Land tenures

Public lands:

The *Crown Lands and Forests Act* is the legal foundation of public (Crown) forest management in New Brunswick. It was proclaimed in 1982 and is administered by the Department of Natural Resources and Energy Development (DNRED). The Act divides New Brunswick's Crown land into 10 timber licenses (forest management units). Crown timber licenses are granted through 25-year forest management agreements to forest companies called Licensees. The New Brunswick government sets management goals and DNRED and third-party auditors evaluate objectives and Licensees on their performance. Five Licensees presently administer the 10 Crown licenses. Each license also has an assigned number of sub-licensee mills who have been allocated annual volumes of Crown timber products.

Parks and protected areas:

In New Brunswick, terrestrial protected areas cover 338,450 ha or 4.7% of the province. The vast majority of this area (290,300 ha) is protected by the province as either Provincial Parks or Protected Natural Areas. The remainder is National Parks, other federal protected areas, and privately owned conservation areas.

Private lands:

Private land in New Brunswick falls into two categories:

(i) Industrial Freehold, which is private land owned by forestry companies; and
(ii) Private Woodlots.

Industrial Freehold is managed on a commercial scale and most companies have had their lands certified by one of the recognized third-party sustainable forest management certification programs. Private lands must conform to the *Clean Water Act*.

More than 40,000 separate owners hold private woodlots in New Brunswick. They are free to manage their woodlots as they deem appropriate and must only conform to the *Clean Water Act*. Seven Forest Product Marketing Boards in the Province offer services to private woodlot owners. The New Brunswick Federation of Woodlot Owners Inc. acts as the liaison between the provincial government and the seven regional Boards. Woodlot owners are subject to Board levies on the sale of forest products and owners may choose to belong to woodlot owner co-operatives, if available. The DNRED and the New Brunswick Federation of Woodlot Owners periodically cooperate to update the provincial private wood supply to help manage long-term sustainability.

2.3 New Brunswick by the numbers

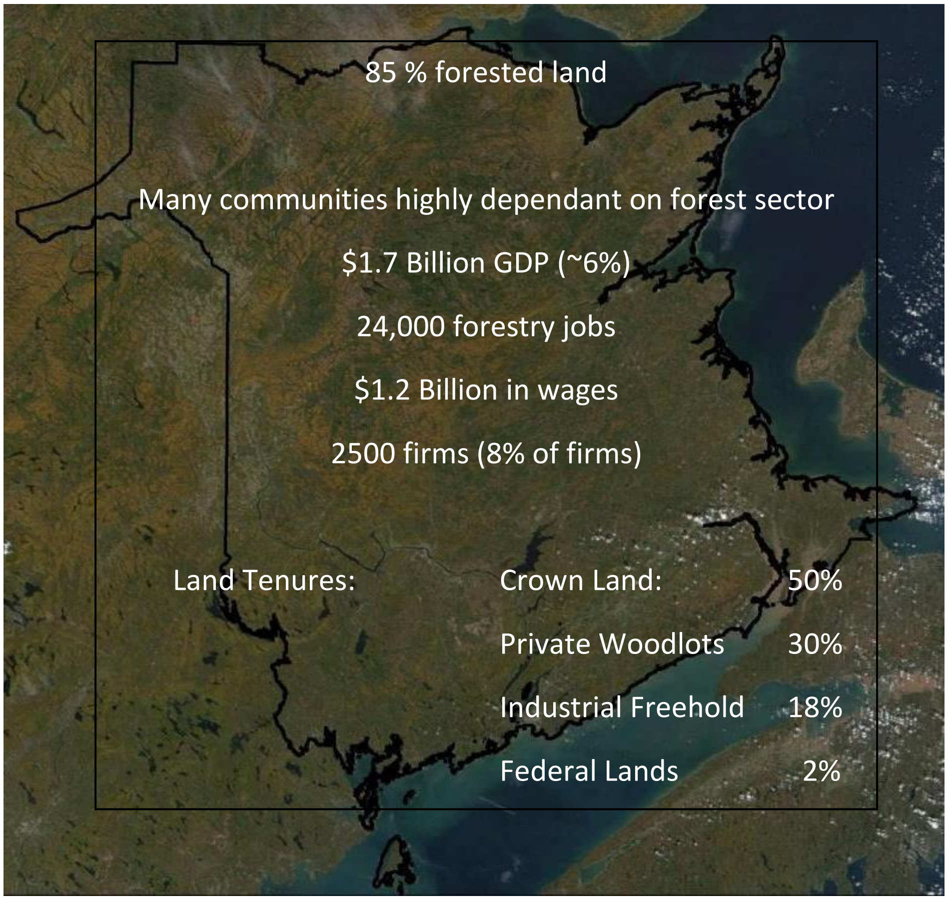


Figure 4. New Brunswick by the numbers

2.4 Forest management legislation and regulations

The provincial government establishes operational standards, policies, and guidelines for forest management on Crown lands. Crown land forest operations are monitored and periodically assessed by DNRED staff under the Results-Based Forestry system. DNRED also evaluates Licensee forest management performance at five-year intervals.

Primary acts and regulations governing Crown forest land in New Brunswick:

Crown Lands and Forest Act
Forest Fires Act
Forest Products Act
Clean Water Act
Transportation of Primary Forest Products Act

2.5 Forest certification

New Brunswick requires that Crown forest lands managed by Timber Licensees be certified under one of the following third-party forest certification systems: Sustainable Forestry Initiative (SFI), Canadian Standards Association (CSA) or Forest Stewardship Council (FSC). At present, all Crown lands managed by Licensees are certified under SFI. Industrial freehold lands controlled or harvested by the Licensees are also certified under SFI. In total 4.2 million hectares are certified to the SFI standard in New Brunswick.

2.6 Duty to consult with Aboriginal Peoples

The Province of New Brunswick has a duty to consult with First Nations when contemplating an action or a decision that may infringe upon proven or asserted Aboriginal and treaty rights. The New Brunswick *Duty to Consult Policy* provides direction to the provincial government for engagement and consultation with Aboriginal peoples in New Brunswick.

The Crown's duty to consult applies to resource management activities including licensing, leasing, permitting, or regulating access to fish, wildlife, forests, minerals or other Crown resources. Additionally, the Duty to Consult Policy extends to the creation, amendment or implementation of regulations, policies, or procedures, including strategic and operating plans, which may have the potential to impact the traditional use of Crown land and resources.

The Government of New Brunswick is committed to fulfilling its legal obligation to actively engage in consultation with First Nations and is dedicated to building long-term relationships that promote increased opportunity for economic development and participation in the natural resource sector.

3.0 FORESTRY IN CANADA

3.1 Canada’s forests by the numbers

Canada’s 347 million hectares (ha) of forest make up 9% of the world’s forests. Twenty-four percent of the world’s boreal forests are found within Canada’s borders. Much of Canada’s forest land is in remote, sparsely populated areas and is not under the same pressure to be cleared for agriculture or urban development as forests in many other countries. Canada has nearly 10 ha of forest land per person, more than 17 times the world average.

To measure Canada’s forest, we need to define “forest.” Canada uses the Food and Agriculture Organization of the United Nations’ definition of forest:

- land spanning more than 0.5 ha
- tree canopy covering more than 10% of the total land area
- trees growing to a height of more than 5 metres

This definition does not include land that is predominantly urban or used for agricultural purposes.

Forest land that temporarily has no trees, for example, after a natural disturbance like fire or after harvesting, is still considered forest, because trees grow back.

Deforestation occurs when forest is converted to a different land use, such as urban development or agriculture. Afforestation is the opposite of deforestation. It means that new forest is created through planting and/or seeding on land that was previously agricultural, urban, or some other non-forested land use. Between them, afforestation and deforestation are drivers of forest area changes.

Canada’s forests by numbers

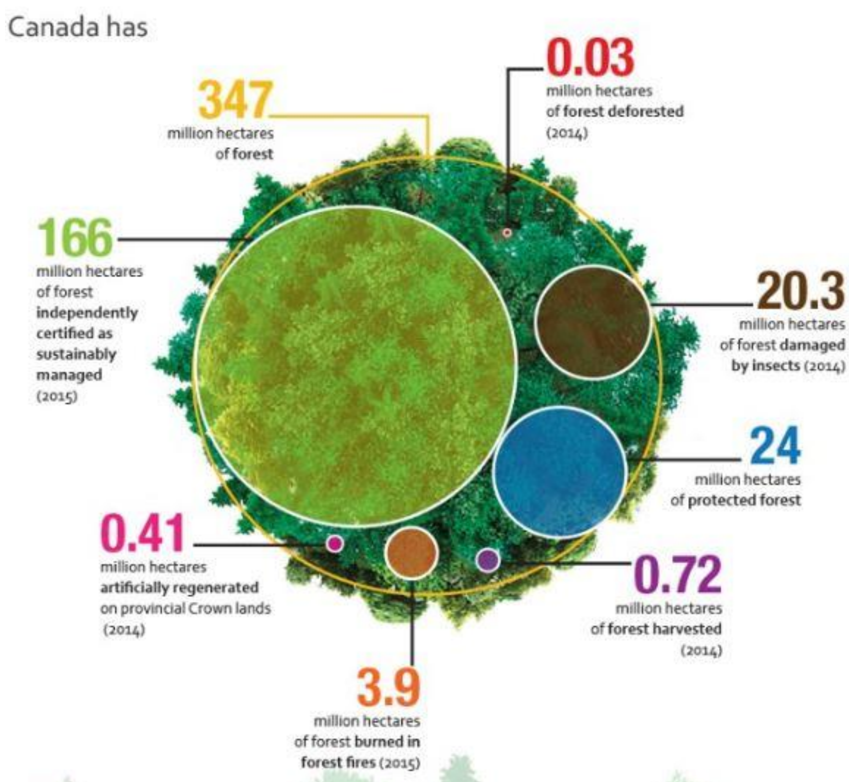


Figure 5. Canada by the numbers (The State of Canada’s Forests Annual Report 2016)

3.2 Forest land ownership in Canada

Most of the Canada's forest land, about 94%, is publicly owned and managed by provincial, territorial and federal governments. Only 6% of Canada's forest lands is privately owned.

This means that all those jurisdictions—provincial, territorial, and federal— have the ability to create and enforce the laws, regulations, and policies required to meet Canada's commitment to sustainable forest management across the country.

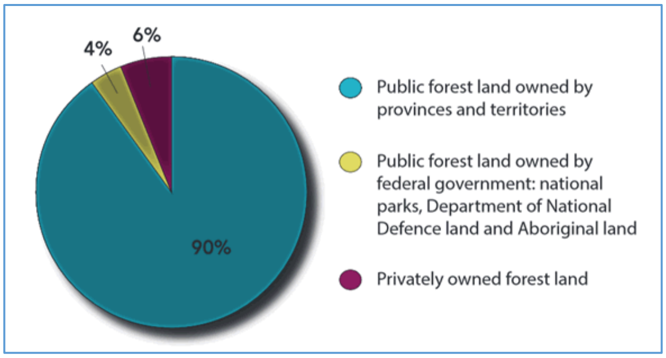


Figure 6. Land ownership in Canada (Natural Resources Canada).

<u>Public forest land owned by provinces and territories: 90%</u>

For the 90% of Canada's forests they own, the provinces and territories have many responsibilities and powers. They:

- Develop and enforce forest laws.
- Set up a license or timber supply agreement with forest companies that want to harvest timber in publicly owned forests.
- Specify the responsibilities of the forest companies that are given access to public forests.
- Monitor the activities of those forest companies to ensure that laws, lease agreements and forest management plans are complied with.
- Collect royalties from forest companies for the timber they harvest from public forests.
- Manage designated protected areas, such as provincial parks and conservation areas.

Forest management planning is a key tool used to ensure that Canada's publicly owned forests remain healthy and vibrant and are managed sustainably.

<u>Public forest land owned by federal government: 4%</u>

The 4% of Canada's forests owned by the federal government are located mainly in national parks, on lands owned by the Department of National Defense, and on lands held in reserve for, or otherwise controlled by, Aboriginal Peoples.

The federal government departments responsible for regulating and managing forestry operations on these lands include:

- Indigenous and Northern Affairs Canada
- Department of National Defense
- Natural Resources Canada
- Parks Canada

<u>Privately owned forest land: 6%</u>

Although only 6% of Canada's forests are privately owned, they contribute substantially to the country's wood products sector.

- This category is made up of large forests owned by forest companies, notably in the provinces of New Brunswick, Nova Scotia, Ontario, Québec, and British Columbia.
- The rest of the private ownership category includes small family-owned forests and woodlots.
- One-tenth of the timber harvested in Canada comes from private lands.

3.3 How much Canada has forested area changed over the years?

Canada's forested area has been quite stable over the past 25 years. Between 1990 and 2016, Canada's forest area decreased by 1.3 million ha (less than half of 1%). Figure 7 shows the causes of deforestation in Canada for the year 2010. Agriculture and industry and resource extraction accounted for 73% of deforestation while urban development, transportation and recreation accounted for an additional 17% while the portion attributed to forest operations (forest roads) was 8%.

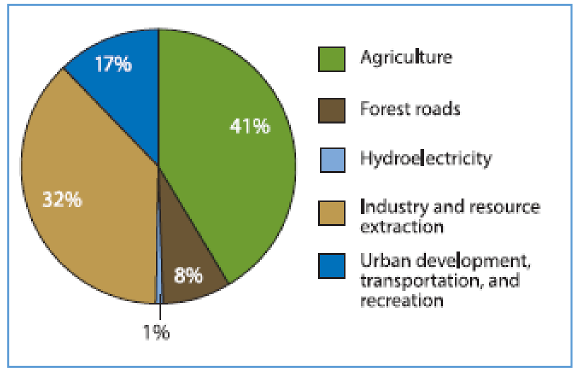


Figure 7. Causes of deforestation in Canada for 2010 (Natural Resources Canada)

While the forest area is relatively constant, forest cover within that area is more dynamic. Forest fires, insect infestations, timber harvesting, growth, and regeneration contribute to the continually changing mosaic of Canada's forest area. However, climate change could change the extent of Canada's forest areas.

Table1. Estimated area (millions of hectares) of forest in Canada. (Natural Resources Canada)

YEAR	1990	1995	2000	2005	2010	2015
Forest area	348.3	348.0	347.8	347.6	347.3	347.1

3.4 Is timber being harvested sustainably?

Timber harvesting is sustainable in Canada thanks to strong laws, oversight and management, and the requirement that all harvested public lands be regenerated.

About 90% of Canada's forests are located on provincial and territorial Crown lands. The provincial and territorial governments are therefore responsible for forest management. They specify an allowable annual cut, which includes both the annual level of harvest allowed on a particular area of Crown lands and the minimum forest age at the time of harvest. Regulating harvest levels in his way helps to ensure sustainability over the long term.

All provincial and territorial lands that are harvested for commercial timber in Canada must be regenerated either naturally or by planting or seeding. Each province and territory have its own regeneration standards and regulations, addressing such areas as species composition, density and stocking level, and the distribution of various forest types across the landscape.

Whether by natural or artificial regeneration, harvested areas grow back. Regeneration ensures that Canada's forests continue to produce wood fibre for commercial uses, offer recreational opportunities and provide ecosystem services, such as storing carbon, regulating water quality, and creating wildlife habitat.

4.0 TREE PHYSIOLOGY AND TREE IDENTIFICATION

4.1 Parts of a tree

Crown
The crown, which consists of the leaves and branches at the top of a tree, plays an important role in filtering dust and other particles from the air. It also helps cool the air by providing shade and reduces the impact of raindrops on the soil below.

The leaves are the food factories of a tree. They contain chlorophyll and give leaves their green colour. Through a process called photosynthesis, leaves use the sun's energy to convert carbon dioxide from the atmosphere and water from the soil into sugar and oxygen. The sugar, which is the tree's food, is either used or stored in the branches, trunk, and roots. The oxygen is released into the atmosphere.

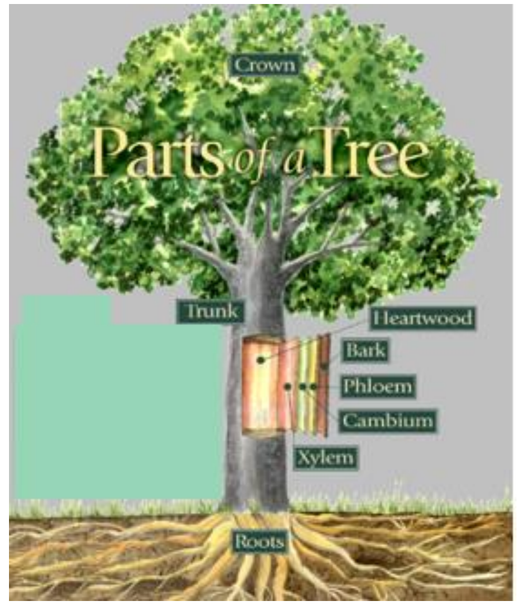


Figure 8. Parts of a tree (North Carolina Forestry Association)

Roots
A tree's roots absorb water and nutrients from the soil, store sugar and anchor the tree upright in the ground. All trees have lateral roots that branch into smaller and smaller roots and usually extend horizontally beyond the branch tips. Some trees have a taproot that reaches down as far as 4 to 5 metres. Each root is covered with thousands of root hairs that make it easier to soak up water and dissolved minerals from the soil. Most of the root system is located in the upper 30 to 50 cm of soil because the oxygen that roots require to function properly is most abundant there.

Trunk/Stem
The trunk, or stem, of a tree supports the crown and gives the tree its shape and strength. The trunk consists of four layers of tissue. These layers contain a network of tubes that runs between the roots and the leaves and acts as the circulatory system for the tree. These tubes carry water and minerals up from the roots to the leaves, and they carry sugar down from the leaves to the branches, trunk, and roots.

> **Heartwood** As a tree grows, older cells in the center of the tree become inactive and die, forming heartwood. Because it is filled with stored sugar, dyes and oils, the heartwood is usually darker than the sapwood. The main function of the heartwood is to support the tree.
>
> **Sapwood** The sapwood comprises the youngest layers of wood. Its network of thick-walled cells brings water and nutrients up from the roots through tubes inside of the trunk to the leaves and other parts of the tree. As the tree grows, sapwood cells in the central portion of the tree become inactive and die. These dead cells form the tree's heartwood.
>
> **Cambium** The cambium is a very thin layer of tissue that produces new cells that become either sapwood, phloem, or more cambium. Every growing season, a tree's cambium adds a new layer of wood to its trunk, producing a visible growth ring in most trees. The cambium is what makes the trunk, branches, and roots grow larger in diameter.

Phloem The phloem is found between the cambium and the outer bark. The phloem acts as a food supply line by carrying sap (sugar and nutrients dissolved in water) from the leaves to the rest of the tree.

Bark The trunk, branches and twigs of the tree are all covered with bark. The outer bark, which originates from old phloem cells, acts as a suit of armor against the world by protecting the tree from insects, disease, storms, and extreme temperatures. In certain species, the outer bark also protects the tree from fire.

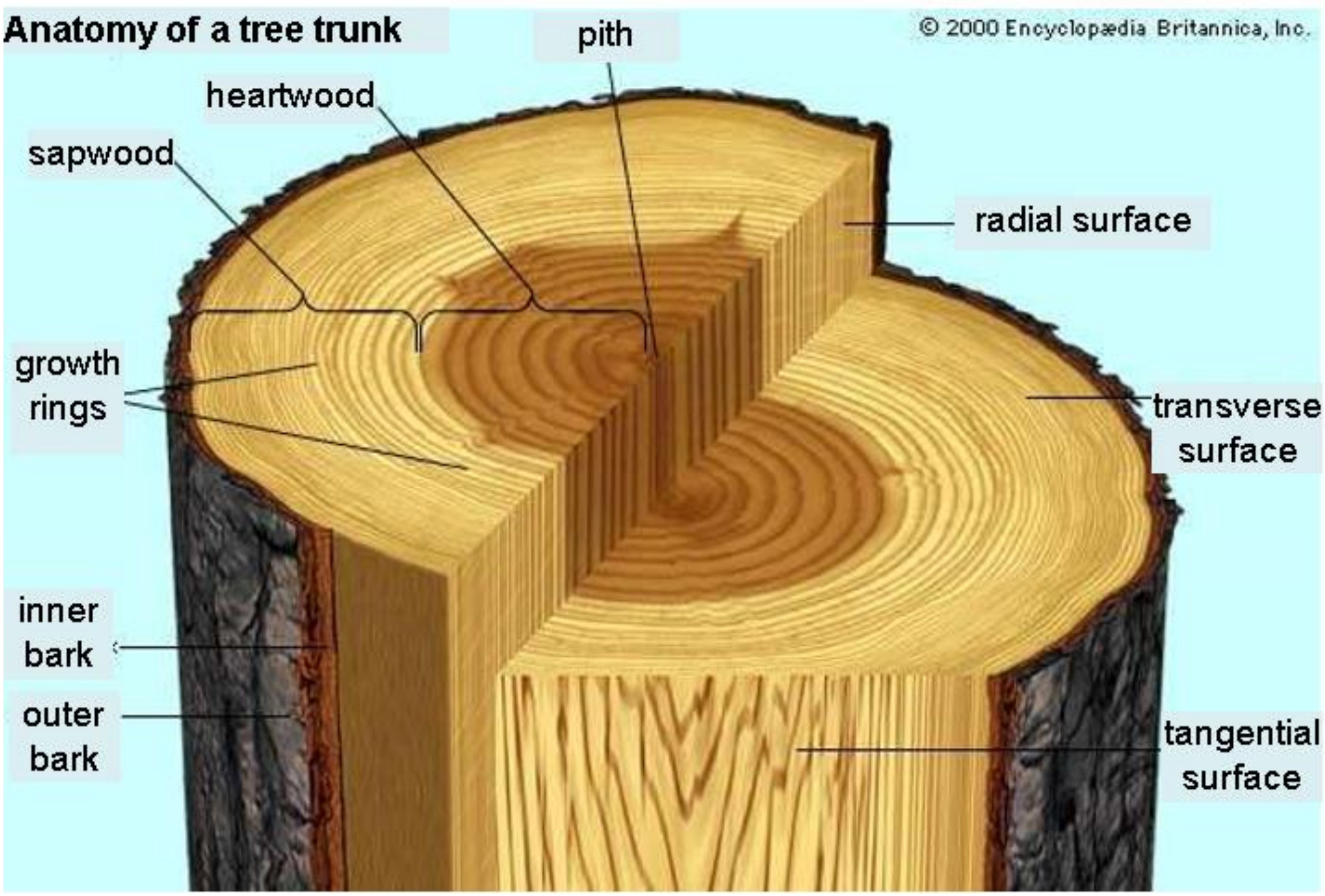


Figure 9. Transverse slice of tree trunk, depicting major features visible to the unaided eye in transverse, radial, and tangential sections (*Encyclopædia Britannica, Inc.)*

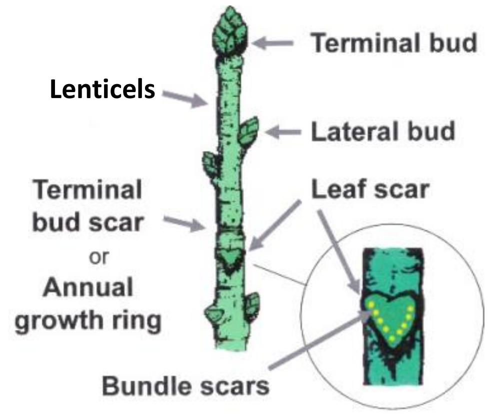
4.2 Plant Structures: Stems

Bud – A stem's primary growing point. Buds can be either leaf buds (vegetative) or flower buds (reproductive). These buds can be very similar in appearance, but flower buds tend to be plumper than leaf buds.

Terminal bud: Bud at the tip of a stem.

Lateral buds: Grow from the leaf axils on the side of a stem.

Leaf scar: Mark left on stem where leaf was attached. Often used in woody plant identification.



Bundle scar: Marks left in the leaf scar from the vascular tissue attachment. Used in woody plant identification.

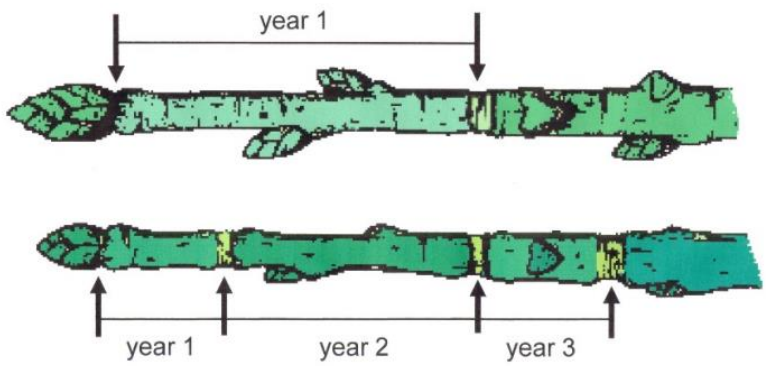
Lenticels: Pores that allow for gas exchange.

Terminal bud scale scars or **annual growth rings:** Marks left on stem from the terminal bud scales in previous years. Terminal bud scale scars are an external measure of annual growth. Therefore, they are important in assessing plant vigour.

Node: Segment of stem where leaves and lateral buds are attached.

Internode: Section of a stem between two nodes.

Bark: Protective outer tissue that develops with age. Used in woody plant identification.



Terminal bud scars or annual growth rings

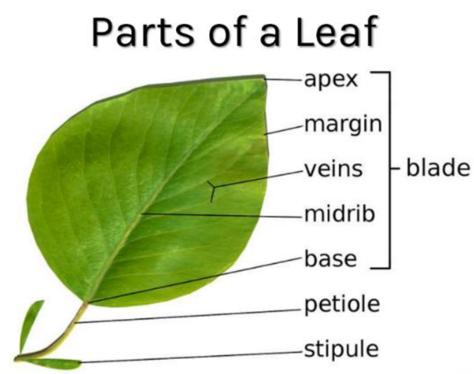
4.3 Plant Structures: Leaves

Leaves are the principal structure, produced on stems, where photosynthesis takes place. Cacti are an exception. The leaves are reduced to spines, and the thick green, fleshy stems are where photosynthesis takes place.

Functions of leaves

- To compete for light for photosynthesis (the manufacture of sugars).
- Evapotranspiration from the leaves to move water and nutrients up from the roots.
- Regulate moisture, gas exchange and temperature through small openings on the leaf, known as stomata.

Parts of a leaf

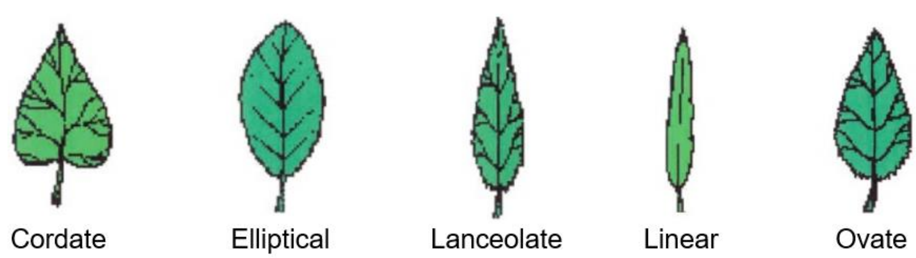


- Blade: consists of the apex, margin, veins, midrib, and base. It is the large, flat part of the leaf where photosynthesis occurs.
- Apex: tip of the leaf
- Margin: edge of the leaf
- Veins: carry food/water throughout leaf; act as a structure support
- Midrib: thick, large single vein along the midline of the leaf
- Base: bottom of the leaf
- Petiole: the stalk that joins a leaf to the stem; leafstalk
- Stipule: the small, leaf-like appendage to a leaf, usually found in pairs at the base of the petiole

Overall leaf shape

Leaf shape is a primary tool in plant identification. Descriptions often go into minute detail about general leaf shape, and the shape of the leaf apex and base. The figure below 4 illustrates some common shapes as used in the Manual of Woody Landscape Plants.

Cordate – heart-shaped
Elliptical – leaf widest in the middle, tapering on both ends
Lanceolate – leaf is 3x or longer than wide and broadest below the middle
Linear- leaf narrow, 4x longer than wide (width remains roughly same)
Ovate- leaf is broadest below the middle and about 2x as long as the width (egg- shaped)



4.4 Photosynthesis

Photosynthesis is the process of through which light energy is used to convert carbon dioxide (CO_2) and water (H_2O) to carbohydrates (sugar).

A primary difference between plants and animals is the plant's ability to manufacture its own food. In photosynthesis, carbon dioxide from the air and water from the soil react with the sun's energy to form *photosynthates* (sugars, starches, carbohydrates, and proteins) and release oxygen as a by-product (Figure 12).

Photosynthesis literally means *to put together with light.* It occurs only in the *chloroplasts*, tiny sub-cellular structures contained in the cells of leaves and. A simple chemical equation for photosynthesis is:

carbon dioxide + water + light energy = glucose + oxygen

6CO2 + 6H2O + light energy = C6H12O6 + 6O2

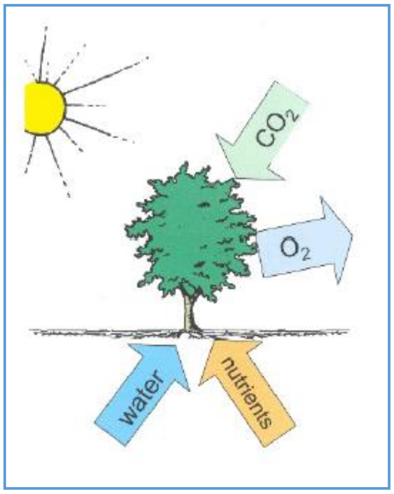


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Figure 10. In photosynthesis, the plant uses water and nutrients from the soil and carbon dioxide from the air, with the sun's energy to create photosynthates. Oxygen is released as a by-product. (Colorado State University Extension)

This process is directly dependent on the supply of water, light**,** and carbon dioxide. Limiting any one of the factors on the left side of the equation (carbon dioxide, water, or light) can limit photosynthesis. For example, a severe drought can reduce photosynthesis and result in a decrease in plant vigour and growth.

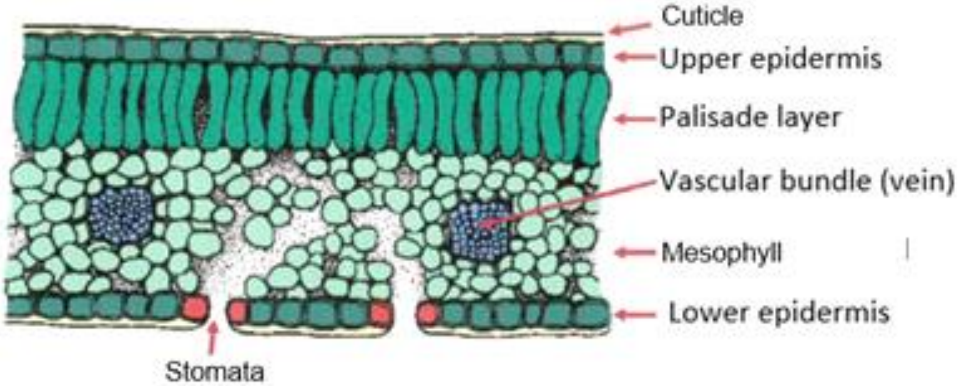
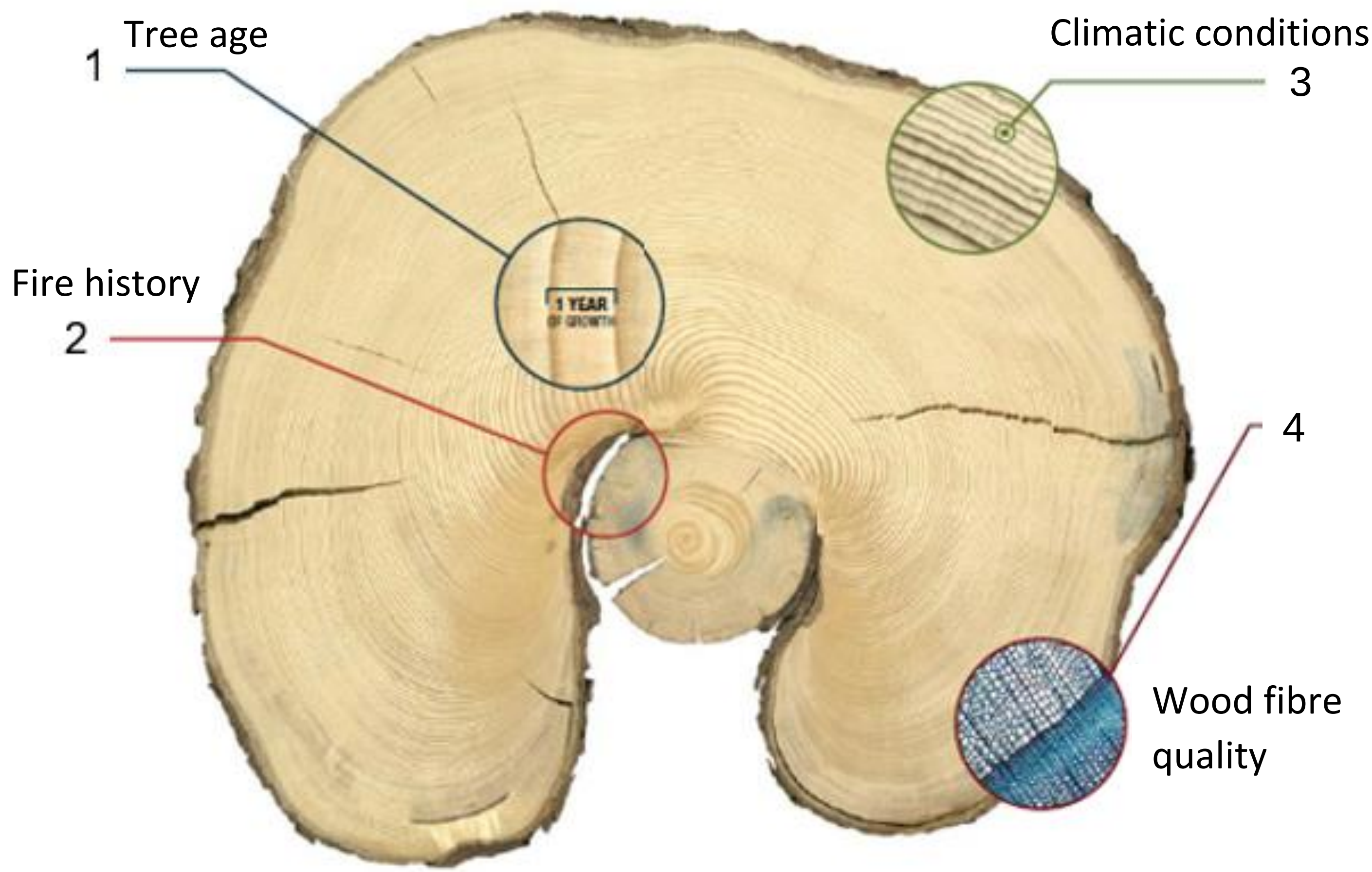


Figure 11. Leaf cross-sectional view with stomata (Colorado State University Extension)

Cuticle:	Waxy protective outer layer of epidermis that prevents water loss from leaves, green stems, and fruits. The amount of cutin or wax increases with light intensity.
Epidermis:	Outer layer of tissues.
Palisade layer:	Layer of tissues filled with chloroplasts.
Vascular bundle:	Xylem and phloem tissues, commonly known as leaf veins.
Mesophyll:	Layer of tissues that facilitates movement of oxygen, carbon dioxide, and water vapour.
Stomata:	Natural openings in leaves and herbaceous stems that allow for gas exchange (water vapor, carbon dioxide and oxygen) and plant cooling.

4.5 Dendrochronology

The science of tree ring analysis is called dendrochronology. Examining the rings in tree cross-sections from cookies or sample cores (which are used more often) can tell you a lot about a tree, its history and the environmental conditions it grew



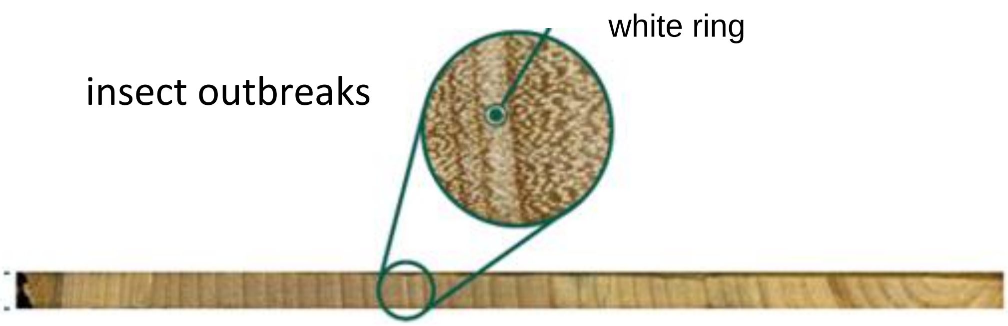
1. Tree age: As trees grow, they form rings made up of a band of light wood produced in the spring (earlywood) and a band of dark wood that forms later in the summer (latewood). This means the wood produced in one year can be measured by the width of one ring of light and dark wood. Counting the number of rings from the outer bark to the centre of the tree—or pith—tells you how old a tree is and is useful for dating historical events in the life of the tree and its surroundings.

2. Fire history: Fire scars occur where a portion of the growing part of the trunk, known as the cambium, is damaged by fire and the tree attempts to cover the wound with new growth. Some fire scars completely heal over, but others remain open (unhealed) due to repeated fires or significant decay of the burned wood—like this one, that occurred when the tree was still young.

3. Climatic conditions: Trees with the right amount of sunlight, rainfall, and ideal temperatures grow faster and produce wider growth rings than trees under stress. Drought, disease, temperatures that are too hot or too cold, and shading or crowding by other trees can slow down tree growth, leaving narrow rings. Studying rings from many trees across the landscape can help scientists understand how the climate may be changing and affecting forest ecosystems over time. The same narrow ring in this tree can be seen in hundreds of other tree samples, suggesting dry soil conditions in late summer of 1984 across parts of Canada's eastern boreal forest.

4. Wood fibre quality: Wood characteristics like density, sound absorption, strength and stiffness are important qualities that determine the suitability of wood for specific products or end uses, from guitars to engineered wood products and pulp used in packaging and textiles. Microscopic views of tree rings—like this one magnified 57 times its normal size—can show irregularities in cells caused by water stress or bending caused by wind and snow. These irregularities can make wood inflexible, weak, or resistant to surface treatment and potentially limits its use for some products. The ability to identify wood fibre qualities of trees before harvest allows forest managers to make better business decisions about what products can be made from the trees growing in a specific forest, and what trees are best suited to plant for future forest products.

5. Insect outbreaks: Severe or repeated defoliation—the stripping of a tree's leaves or needles—by insects such as the forest tent caterpillar is stressful to the tree and causes a marked slowing of growth that can be seen in the pale annual growth ring of this trembling aspen core. This "white ring" is of lower density than the wood the tree produced before defoliation and after recovery. Studying the occurrence of white rings in many trees helps scientists to better understand the impacts of forest tent caterpillar outbreaks on aspen forest productivity, how insect populations change over time and how ecosystems respond to outbreaks.



Trees are rarely cut down for tree ring analysis. Instead, a tool such as an increment borer is used to extract a core sample of wood, extending from the bark to the centre of the tree. This trembling aspen was about 60 years old when sampled.

4.6 Tree Identification

4.6.1 Twig and Cone Key for Softwood Trees of the Acadian Forest

1. Leaves not needle-like..2

2. Small, flat, scale-like leaves, soft, yellow-green in colour, 1-2 mm long; cones egg-shaped, 7-12 mm long. ....*Eastern white cedar*

1. Leaved needle-like...3

3. Needles in bundles or groups..4

4. Two needles in each bundle..5

5. Needles straight, 10-16 cm long, needles will break or snap when bent; cones roundish, 4-7 cm long, cone scales thicker at tips..*Red pine*

5. Needles yellow-green, 2-4 cm long, divergent (split apart) and twisted; cones 3-7 cm long, serotinous, usually curved..*Jack pine*

4. More than two needles in each bundle...6

6. Needles in bundles of 5, 10-15 cm long, soft, blue-green; cones 8-20 cm long, cone scales broader towards tip..*Eastern white pine*

6. Needles 15-60 per bundle, soft, bluish-green colour, deciduous; cones roundish, 10-15 mm long, attached to twig by a curved stalk (petiole)...*Tamarack*

3. Single needles..7

7. Needles flattened (do not roll between fingers)..8

8. Needles glossy green above with two white bands and three darker bands below, attached to twig by short stalk (petiole); cones egg-shaped, 12-20 mm long ....*Eastern hemlock*

8. Needles dark green above with two white lines and one dark line below. Fragrant odour when crushed; cones cylindrical, erect, 4-10 cm long, break apart when seeds are mature leaving a vertical spike...*Balsam fir*

7. Needles 4-sided (roll between fingers)..9

9. Needles yellow-green, curved; cones egg-shaped, 3-5 cm long, cone scales stiff, margin usually not toothed or serrated..*Red spruce*

9. Needles straight, dull greyish-green; cones 2-3 cm long, cone scales toothed or serrated and brittle...*Black spruce*

9. Needles straight, stiff, pungent odour when crushed, bluish-green; cones 3-6 cm long, cone scales are pliable when squeezed ....*White spruce*

Balsam fir

Tamarack

Eastern hemlock

White spruce

Black spruce

Red spruce

Jack pine

White pine

Red pine

Eastern white cedar (cedar)

4.6.2 Leaf Key for Hardwood Trees of the Acadian Forest

1. Leaves opposite………2

2. Leaf simple……….3

2. Leaf compound…….6

3. Five distinct lobes, leaf edge wavy, leaf sinuses "u-shaped"………………………………………………………*__Sugar maple__*

3. Three to five lobes, leaf edge toothed……………………………………………………………………………………4

4. Underside of leaf not silvery, leaf edge double toothed…………………………………………………………*__Striped maple__*

4. Underside of leaf silvery……………………………………………………………………………………………………5

5. Leaf sinuses deeply lobed and "u"-shaped……………………………………………………………………*__Silver maple__*

5. Leaf sinuses notched "v-shaped"……………………………………………………………………………………*__Red maple__*

6. Leaf compound……7

7. 5-9 leaflets, leaflets stalked, egg-shaped to lance-shaped leaflets, leaf edge smooth or wavy……………*__White ash__*

7. 7-11 leaflets, leaflets not stalked, finely and sharply toothed leaf edge…………………………………………*__Black ash__*

7. 5-9 leaflets on a hairy central stalk, hairy underneath, leaf edge smooth towards base of leaf and toothed towards tip ………………………………………………………………………………………………………*__Green ash__*

1. Leaves not opposite……8

8. Leaf compound, 11 to 17 finely toothed leaflets…………………………………………………………………*__Butternut__*

8. Leaf simple………9

9. Leaf edge double toothed…………………………………………………………………………………………………10

9. Leaf edge not double toothed……………………………………………………………………………………………11

10. Leaf shape triangular……………………………………………………………………………………………………*__Gray birch__*

10. Leaf shape not triangular………………………………………………………………………………………………12

12. Underside of leaf rough, leaf base asymmetrical………………………………………………………………*__White elm__*

12. Underside of leaf not rough, leaf base not asymmetrical…………………………………………………………13

13. 7-9 veins, leaf edges coarsely double toothed except near stem, bark white and peeling ……..*__White birch__*

13. 9-13 veins, leaf edges coarsely double toothed, bark yellow…………………………………………*__Yellow birch__*

13. Leaf stem short, finely double toothed, leaf feels thin…………………………………………………………*__Ironwood__*

11. Leaf stem (petiole) flat……14

11. Leaf stem (petiole) not flat……………………………………………………………………………………………………15

14. Large teeth……*__Largetooth aspen__*

14. Small teeth……*__Trembling aspen__*

15. Leaf lobed……16

15. Leaf not lobed………17

16. Several pointed teeth on each lobe………………………………………………………………………………*__Red oak__*

16. Lobes rounded (not pointed)…………………………………………………………………………………………*__Bur oak__*

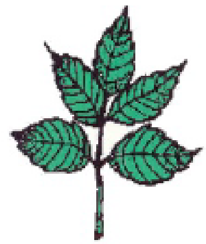
17. Leaf edge coarsely toothed……………………………………………………………………………*__American beech__*

17. Leaf edge fine toothed………………………………………………………………………………………………18

18. Leaf heart-shaped…………………………………………………………………………………………………*__Basswood__*

18. Leaf egg-shaped, dark green, shiny, rusty blotches on underside of leaf……………..*__Balsam poplar__*

Simple leaf



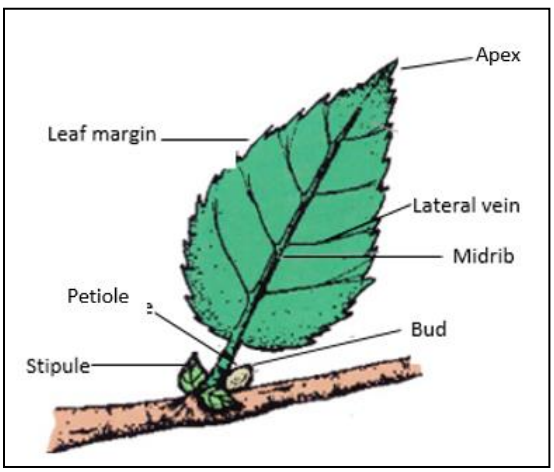
Compound leaf

Leaves alternate

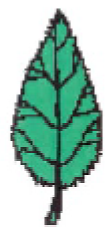
Leaves opposite

Simple leaf: A single blade attached to the stem by a petiole (birches, poplars)
Compound leaf: Leaf composed of several leaflets attached to the stem by a petiole (ashes, butternut)
Leaves alternate: Arranged in staggered fashion along stem (birches, poplars, oaks)
Leaves opposite: Pair of leaves arranged across from each other on stem (maples, ashes)

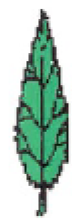
PARTS OF A LEAF



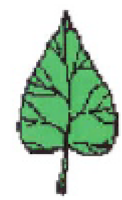
LEAF FORMS



Oval



Lanceolate



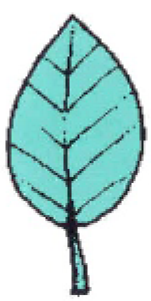
Cordate

Ovate : leaf is broadest below the middle and about 2x as long as the width (egg-shaped)

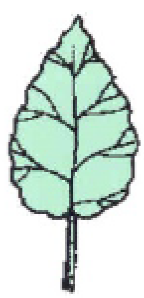
Lanceolate: leaf is 3x or more longer than width and broadest below the middle

Cordate: leaf is heart-shaped

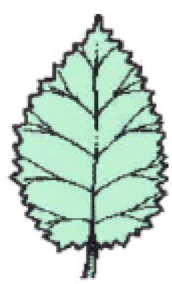
LEAF MARGINS



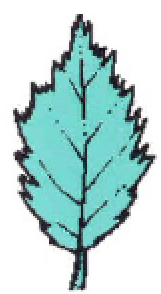
Entire



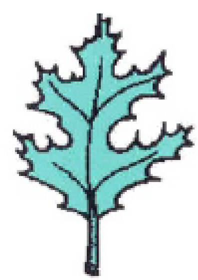
Crenate



Dentate



Doubly serrate



Incised

Lobed

Entire: leaf edge is smooth
Crenate: leaf edge has blunt, rounded teeth
Dentate: leaf has triangular or tooth-like edges
Doubly serrate: edges with saw like teeth that have even smaller teeth within the larger ones
Incised: leaf margins have deep, irregular teeth
Lobed: leaf edges are deep and rounded

5.0 FOREST ECOLOGY

5.1 Crown classes

Crown class is a term used to describe the position of an individual tree in the forest canopy. In the definitions below, “general layer of the canopy” refers to the bulk of the tree crowns in the size class or cohort being examined. Crown classes are most easily determined in even aged stands, as shown in Figure 12. In an uneven aged stand, a tree’s crown would be compared to other trees in the same layer.

- **Dominant trees:** These crowns extend above the general level of the canopy. They receive full light from above and some light from the sides. Generally, they have the largest, fullest crowns in the stand.
- **Codominant trees:** These crowns make up the general level of the canopy. They receive direct light from above, but little or no light from the sides. Generally, they are shorter than the dominant trees.
- **Intermediate trees:** These crowns occupy a subordinate position in the canopy. They receive some direct light from above, but no direct light from the sides. Crowns are generally narrow and/or one-sided, and shorter than the dominant and codominant trees.
- **Suppressed trees (overtopped trees):** These crowns are below the general level of the canopy. They receive no direct light. Crowns are generally short, sparse, and narrow.

Figure 12. An illustration of crown classes. “D” = Dominant; “C” = Codominant; “I” = Intermediate and “S” = Suppressed (Creative Commons).

Crown classes are a function of tree vigour, tree growing space, and access to sunlight. These in turn are influenced by stand density and species shade tolerance.

Crown class distribution can also infer overall vigour of an even aged stand. If most trees are in the intermediate crown class, the stand is likely too crowded, and the trees are stagnated. A stand with nearly every tree in the dominant category is either very young, with all the trees receiving plenty of sun, or very sparse and may be considered “understocked.” A typical even aged stand has most trees in the codominant class, and the fewest trees in the suppressed class. The relative ratios of dominant and intermediate classes are generally a function of species composition.

5.2 Forest regions of Canada

A **forest region** is defined as a major geographic belt or zone characterized by a broad uniformity in physiography and in the composition of dominant tree species. Different forest regions exist because of differences in soil types, topography, climate, and precipitation. Canada has eight forest regions; each geographically characterized by dominant species and stand types of vegetation.

Boreal Forest Region

Approximately 80 per cent of Canada's forested land is in the immense boreal forest region, which swings in an arc south from the Mackenzie River Delta and Alaskan border to northeast British Columbia, across northern Alberta and Saskatchewan, through Manitoba, Ontario, and Québec terminating in northern Newfoundland on the shores of the Labrador Sea. The northern boreal region consists of open forest with trees growing farther apart and smaller in size as the forest stretches towards the tundra, where only dwarf specimens persist.

The southern boreal region presents a denser, closed forest, which, at its southwest boundary in the Prairie Provinces, gives way to a transitional zone dominated by poplar. Known as the aspen grove, this part of the forest thins out into open, almost treeless prairie. White and black spruce are the principal species of the predominantly coniferous boreal forest, but other conifers (e.g., balsam fir, jack pine, and tamarack) also have a wide distribution. There is a general mixture of broad-leaved trees in the region, including white birch, balsam poplar, and the wide-ranging trembling aspen.

Great Lakes-St. Lawrence Forest Region

Although it is less than one-tenth the size of the boreal forest, the Great Lakes-St Lawrence Forest Region is Canada's second-largest forest region. Except for a 322 km gap where the boreal region touches the north shore of Lake Superior, this forest stretches from southeastern Manitoba to the Gaspé Peninsula. It is bordered to the south by the deciduous forest region and is a transitional forest between the coniferous and broad-leaved regions. Characteristic species are eastern white pine, red pine, eastern hemlock, and yellow birch. Sugar maple, red maple, beech, red oak, basswood, and white elm are also found, as are many boreal species.

Acadian Forest Region

Closely related to the Great Lakes-St Lawrence Forest Region, this Acadian Forest Region is confined to Nova Scotia, Prince Edward Island, and a large portion of New Brunswick. Red spruce, balsam fir, yellow birch, and sugar maple are commonly found. Black spruce, white birch, grey birch, red oak, white elm, black ash, beech, red maple, trembling aspen, and balsam poplar are also widely distributed.

Deciduous Forest Region

The Deciduous Forest Region is Canada's smallest forest region. It borders the southeast shore of Lake Huron and the northern shores of Lakes Erie and Ontario. Despite its small size, this region contains the largest number of native tree species of any region. Along with the broad-leaved trees common to the Great Lakes-St Lawrence Forest Region are found the cucumber tree, tulip tree, black gum, blue ash, sassafras, black walnut, and others, which are at the northern limits of their range. Conifers occur only as a scattering of eastern white pine, tamarack, eastern red cedar, and eastern hemlock.

Coastal Forest Region

This region covers the lower seaward slopes of British Columbia's Coast Mountains and extends to the coastal islands. Characteristic species are western hemlock, Douglas-fir, western redcedar, and Sitka spruce, all renowned for their value as timber-producing trees. By comparison, the region's broad-leaved trees (e.g., black cottonwood, red alder, big-leaf maple) have a limited distribution and are of minor economic importance.

Subalpine Forest Region

The Subalpine Forest Region is composed of coniferous forests and is situated on the mountain uplands of British Columbia and western Alberta. Characteristic trees are Engelmann spruce, alpine fir, and lodgepole pine, while occasional species include western larch, whitebark pine, and limber pine, together with yellow cypress and mountain hemlock on the more westerly ranges. The subalpine region makes an impressive contribution to the scenic splendour of the Canadian Cordillera and offers unique features of watershed protection and stream control in high-mountain source areas. The trees at lower elevations are harvested for timber.

Montane Forest Region

This region includes British Columbia's central plateau and several valley pockets adjacent to the Alberta boundary, areas which share a prevailing dry climate. The characteristic tree of this region is the Rocky Mountain Douglas-fir, a smaller variety of the coast-region type. Lodgepole pine and trembling aspen are generally present and white spruce is found in cooler, shaded valley locations. In southern parts of the region's more open forest, ponderosa pine is common. Engelmann spruce, alpine fir, and white birch are important species of this region's northern limits.

Columbia Forest Region

This region lies in southeast British Columbia between the Rockies and the central plateau and fingers its way through the subalpine region along river valleys and lakes. The forest of this interior wet belt strongly resembles that of the coast region, although fewer species occur in the interior. Characteristic trees are western red cedar and western hemlock. The Rocky Mountain Douglas-fir is widely distributed, and in southern parts western white pine, western larch, grand fir, and western yew are found. Engelmann spruce is found in the upper Fraser Valley and occasionally at higher elevations in the region.

5.3 Forest succession

Fire, along with disease, insect infestation, and weather (i.e. snow, ice, wind, and lightning) are major environmental disturbances that alter ecosystems. Destructive as they may seem, they leave in their wake space for new plants to grow. A gradual and complex series of changes (both biotic and abiotic) called **succession** must occur to re-establish the forest.

Succession is the directional change in vegetation resulting from the interactions between the living and the nonliving factors of the environment. New plants germinate, grow, and reproduce to successfully inhabit the vacant ecological niche. As the plants increase in size and in number, competition and environmental change begin to change the ecosystem. A new series of plants germinate, grow, and reproduce to repeat the cycle of change. The rate of change becomes more gradual with time until the system stabilizes. This is the final stage of succession in the ecosystem and is called the **climax**. However, it must be emphasized that forests are complex, dynamic communities that are continually evolving at varying rates. Even a climax community is constantly undergoing changes. At any time in the series of changes from the beginning to the climax, a new disturbance may interrupt the series and create a new beginning.

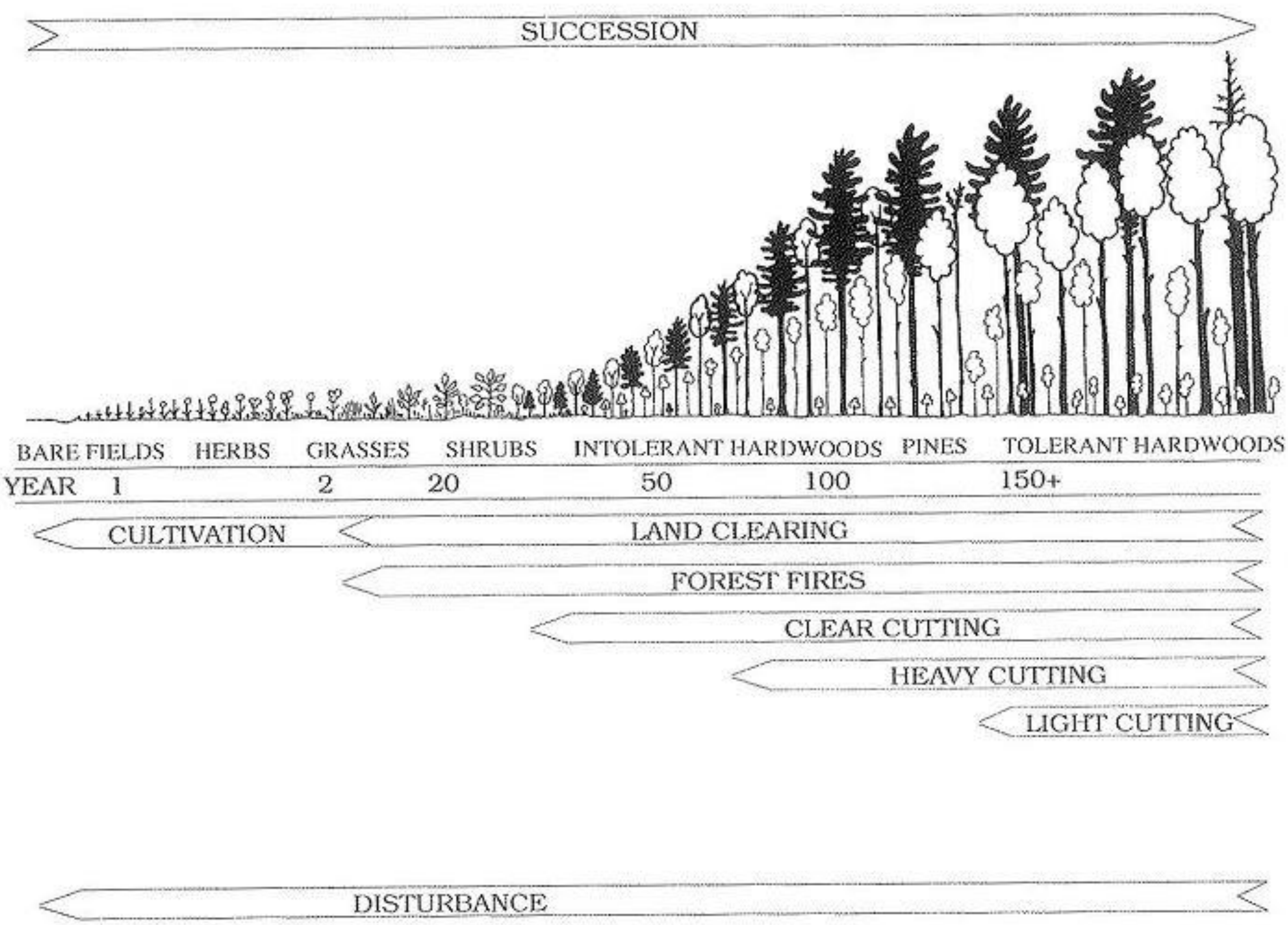


Figure 13. Stages of succession (Focus on Forests)

There are two major forms of succession: primary succession and secondary succession.

Primary succession begins on bare areas that did not previously support vegetative growth. These may be areas of water, sand, or rock. Primary succession begins with soil building. Soils develop from primitive plants called colonizers reacting with the rock over long periods of time to eventually provide bits of soil that, in time, will support larger vegetation. With the accumulation of soil, new plants germinate, grow, and reproduce to begin the stages of a new succession.

Secondary succession occurs in areas in which vegetation does grow, but which have been altered by such external forces as fire, logging, and land clearing. New plants germinate, grow, and reproduce to begin the cycle to the forest stage.

5.4 Shade tolerance

Shade tolerance is the relative capacity of tree species to compete for survival under shaded conditions. It is a tree trait, a functional adaptation that varies among species. Because of its pronounced influence on tree survival and stand growth, shade tolerance is a pillar of silviculture.

Shade tolerance in trees ranges along a continuum from very shade intolerant to very shade tolerant. Foresters often consider shade tolerance when deciding which silvicultural prescription is best for a given species.

It is important to understand that shade tolerance is not the same as shade preference as most plant species grow well, and in most cases even prefer, full light conditions. Being shade tolerant means that they have a competitive advantage when shade conditions exist. For these species, a bit of shade makes them more competitive than they would be under more light because they can outgrow less shade-tolerant species. They compete better in shade.

Figure 14. Understory of shade-tolerant sugar maple regeneration under sugar maple stand (Photo credit: Natural Resources Canada)

Shade-tolerant species, such as eastern hemlock and American beech, can become established and survive on less than 5 percent full light. They typically have longer crowns with lower branches that stay foliated longer than intolerant species. They generally grow slowly and live long. By contrast, shade-intolerant species, such as trembling aspen and red pine, may require as much as 60 percent of full light to remain competitive. Typically, they have shorter, more open crowns, and grow in lower stand densities. They tend to mature early, fruit sooner, and die younger. There is also a class of intermediate shade-tolerant species. Yellow birch and white pine, for instance, work the middle ranges of light availability, remaining competitive with 10 to 30 percent of full light. Many species that are intermediate in shade tolerance germinate and establish under the existing forest canopy, where they will wait until a local disturbance provides new light, at which point they can respond with accelerated growth to fill a gap in the canopy.

Table 2. Shade tolerances of tree species native to New Brunswick

Intolerant	Intermediate	Tolerant
White birch,	Red oak	Eastern hemlock
Trembling aspen	White ash	Northern white cedar
Largetooth aspen	White pine	Sugar maple
Jack pine	Yellow birch	American beech
Red pine	White spruce	Red spruce
Tamarack	Basswood	Balsam fir

5.5 Forest soils

Soils have provided the foundation for trees and entire forests over millions of years. Soil is an important component of forest and woodland ecosystems as it helps regulate important ecosystem processes, such as nutrient uptake, decomposition, and water availability. Soils provide trees with anchorage, water, and nutrients. In turn, trees as well as other plants and vegetation, are an important factor in the creation of new soil as leaves and other vegetation rot and decompose.

Figure 15. Forest soil profile (Photo credit Natural Resources Canada)

However, the relationship between soils and forests is much more complex and far ranging. Soils and forests are intrinsically linked, with huge impacts on each other and on the wider environment. The interactions between forests and forest soils help to maintain the environmental conditions needed for agricultural production. These positive effects are far reaching and ultimately help to ensure a productive food system, improved rural livelihoods and a healthy environment in the face of change.

The world´s forests act as a significant carbon sink. 650 billion tons of carbon, or nearly one third of the total in terrestrial ecosystems, are captured in forests. Forest soils also store a quantity of carbon equaling that of the global forest biomass, about 45 percent each. An additional ten percent of carbon is found in forest dead wood and litter. In total, forests store as much carbon as the atmosphere.

The planet needs sustainably managed forests to control soil erosion and to conserve soil. Tree roots stabilize ridge, hill, and mountain slopes and provide the soil with the necessary mechanical structural support to prevent shallow movements of land mass: landslides rarely occur in areas with high forest cover.

By reducing soil erosion and the risk of landslides and avalanches, sustainably managed forests contribute significantly to the systems providing and maintaining the planet's supplies of clean water, while also ensuring a balanced water cycle.

Forests are also a key component of watershed management—an integrated approach of using natural resources in a geographical area drained by a watercourse. Watershed management is a very sound way to protect and rehabilitate areas prone to soil degradation and erosion in upland areas. Forest and soil characteristics are among the key parameters assessed in watershed management planning. Moreover, measures to restore and enhance soil fertility, e.g. through reforestation, have many benefits and are therefore an integral part of any watershed management plan.

5.6 Forest fires

Fire in Canada's forests varies in its role and importance.

In the moist forests of the west coast, wildland fires are relatively infrequent and generally play a minor ecological role.

In boreal forests, the complete opposite is true. Fires are frequent and their ecological influence at all levels—species, stand and landscape—drives boreal forest vegetation dynamics. This in turn affects the movement of wildlife populations, whose need for food and cover means they must relocate as the forest patterns change.

The boreal: A forest shaped by fire

The Canadian boreal forest is a mosaic of species and stands. It ranges in composition from pure deciduous and mixed deciduous-coniferous to pure coniferous stands.

The diversity of the forest mosaic is largely the result of many fires occurring on the landscape over a long period of time. These fires have varied in frequency, intensity, severity, size, shape, and season of burn.

This photo sequence shows:

1 a fire,
2 the regrowth of aspen 1 year after fire,
3 burned tree with black-backed woodpecker, 1 year after fire,
4 a 50-year stand,
5 a 100-year stand,
6 150 years of growth,
7 old-growth forest (with gap dynamics)

The biodiversity of northern circumpolar boreal forests is largely a fire induced diversity—sometimes termed "pyrodiversity".

How various boreal species respond to fire

Fire strongly influences the structure, growth, and renewal of many of Canada's forest and grassland communities. Different species, however, respond differently to fire.

After a fire, forest regeneration on burned sites begins with the establishment of pioneer species, notably aspen, white birch, jack pine, and lodgepole pine. All these species require full sunlight to thrive, and all are well adapted to landscapes where fires regularly recur.

Aspen and birch can re-establish quickly by sprouting from stumps and roots of burned trees. These species are also able to recolonize burned sites by producing abundant seeds that can be blown by wind over long distances.

Black spruce, with its semi-serotinous cones may also become established in the years following a fire, but this species grows slower in full sunlight than the pioneer species do. If fire does not occur for more than 100 years, the early pioneer trees eventually die and become replaced by the black spruce growing in the understory. Shade tolerant species then establish under the shady cover.

Species such as balsam fir, white spruce, and cedar have no special adaptations to fire. They can colonize burned areas only by coming in from unburned refugia. This might occur, for example, when the seeds of these species are blown into a burned area by the wind or carried by animals. As a result, these species take a long time to reappear in burned stands after a fire—in some cases, as long as 150 years. Because extensive fires place balsam fir and cedar at a disadvantage, these species are rare in areas that are repeatedly severely burned or where fires are large.

Fire is a vital ecological component of Canadian forests and will always be present. The ongoing challenge for fire management agencies is therefore how to manage fire to protect human values while still allowing fire to play its important ecological role in maintaining healthy forests.

Fire behaviour refers to the way fuel ignites, flames develop and fire spreads. In wildland fires, this behaviour is influenced by how fuels (such as needles, leaves and twigs), weather, and topography interact.

Once a fire starts, it will continue burning only if heat, oxygen, and more fuel are present. Together, these three elements make up the “fire triangle.”

To put out a fire requires eliminating one or more of the fire triangle’s elements. Firefighters work to do that by:

- cooling fuels below the combustion temperature with water, foam, retardant, or dirt
- cutting off the oxygen supply with water, retardant, or dirt
- removing fuel by clearing a swath of trees and brush ahead of the advancing fire

There are three basic types of forest fires:

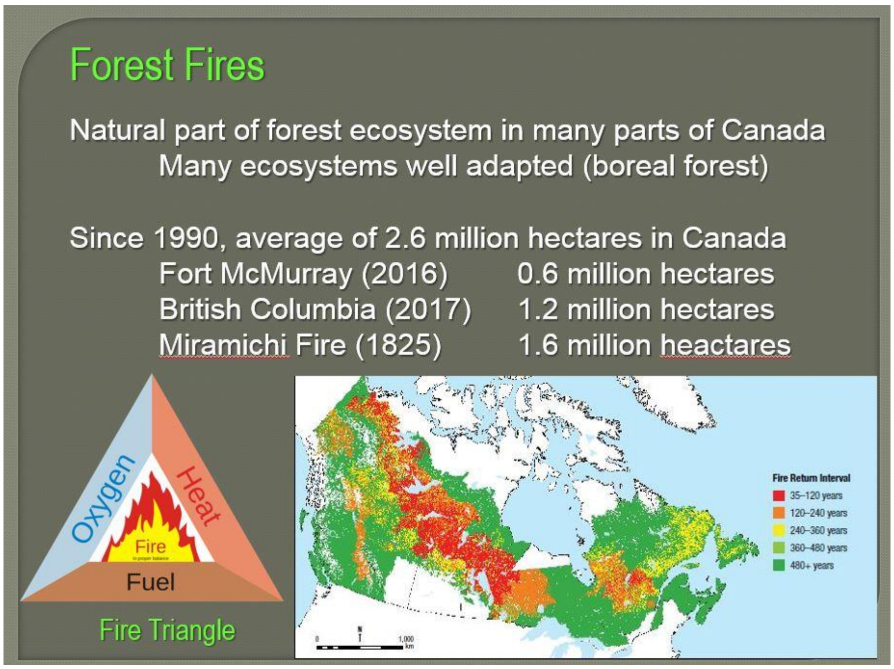
1. **Crown fires** burn trees up their entire length to the top. These are the most intense and dangerous wildland fires.
2. **Surface fires** burn only surface litter and duff. These are the easiest fires to put out and cause the least damage to the forest.
3. **Ground fires** (sometimes called underground or subsurface fires) occur in deep accumulations of humus, peat and similar dead vegetation that become dry enough to burn. These fires move very slowly, but can become difficult to fully put out, or suppress. Occasionally, especially during prolonged drought, such fires can smoulder all winter underground and then emerge at the surface again in spring.

The fire season generally runs from April to October, with the peak of activity occurring from mid-May to August. Catastrophic fires tend to occur during periods of extended drought or windstorms.

Lightning strikes cause slightly less than half of all wildland fires in Canada, but account for nearly 67% of the land area burned. There are two main reasons for this:

- Lightning-caused fires often occur in remote areas where human life, property and timber values are not threatened. Fire suppression in these areas may therefore be intentionally limited, leaving fire to play its natural role.
- Several lightning fires can be ignited simultaneously, leaving agencies with difficult decisions about where to send available firefighting crews and equipment.

Humans cause slightly more than half of all wildland fires in Canada, typically in populated forest and grassland areas. Because of where these fires occur, they are usually spotted early and can be reached quickly by firefighting crews. Still, the threat they pose to human safety and property makes them a major concern for firefighting crews.



Source: G.R. Morrison.

2023 is proving to be Canada's worst fire season ever recorded. As of October 6, 6,551 fires had burned 18.5 million hectares which is an area more than twice the size of New Brunswick and represents about 5% of Canada's forested land.

5.7 Forest ecosystem products and services

Forests play a vital role in Canada's economic health with the forest industry accounting for some 297, 000 direct and indirect jobs.
At the same time, forests also store carbon, preserve soils, and nurture a diversity of species. These non-timber benefits are known as "ecosystem services".

Canadians increasingly recognize the many ecosystem services provided by forests and resource agencies are starting to assess and estimate forests' economic, social, and environmental values.
The benefits provided by forest ecosystems include:

- Goods such as timber, food, fuel and bioproducts
- Ecological functions such as carbon storage, nutrient cycling, water and air purification, and the maintenance of wildlife habitat
- Social and cultural benefits such as recreation, traditional resource uses and spirituality

The first challenge to achieve sustainable forest management is finding ways to continue to benefit from ecological services without compromising the forest's ability to provide those services.

6.0 FOREST MANAGEMENT

A silviculture system covers all management activities related to growing forests—from early planning through harvesting, replanting, and tending the new forest. Forest managers consider a variety of ecological, economic, and social factors when choosing a silviculture system.

A typical silviculture system (BC Ministry of Forests)

A silviculture system is a planned program of silvicultural treatments designed to achieve specific stand structure characteristics to meet site objectives during the whole life of a stand. This program of treatments integrates specific harvesting, regeneration, and stand tending methods to achieve a predictable yield of benefits from the stand over time. Naming the silvicultural system has been based on the principal method of regeneration and desired age structure.

A silvicultural system generally has the following basic goals:

- Provides for the availability of many forest resources (not just timber) through spatial and temporal distribution.
- Produces planned harvests of forest products over the long term.
- Accommodates biological/ecological and economic concerns to ensure sustainability of resources.
- Provides for regeneration and planned seral stage development.
- Effectively uses growing space and productivity to produce desired goods, services, and conditions.
- Meets the landscape- and stand-level goals and objectives of the landowner (including allowing for a variety of future management options).
- Considers and attempts to minimize risks from stand-damaging agents such as insects, disease, and windthrow.

6.1 Even aged management system

Trees in even-aged stands are of the same age or almost the same age. Natural even-aged forests occur after a major disturbance such as fire or insect epidemics such as spruce budworm. Many fire-origin even-aged stand are still present in New Brunswick. Most of these stands are softwood and consist mainly of a single species—jack pine and black spruce being the most common. Even-aged stands generally have a well-developed canopy with a regular top at a uniform height.


Even-aged stand
(BC Ministry of Forests)

Pure even-aged stands generally have a nearly bell-shaped diameter distribution. This means that most trees are in the average diameter class. However, diameter distributions should be viewed cautiously since diameter can be a poor criterion for age. The smallest trees in natural even-aged stands are generally spindly, with vigour suppressed by the overstorey.

Even-aged stands can develop from the following silvicultural systems:

- Clearcut
- Patch cut
- Seed tree cut
- Coppice method
- Shelterwood cut

6.1.1 Clearcut

A "clearcut" means a silvicultural system that:

Removes the entire stand of trees in a single harvesting operation from an area that is:

i) one hectare or greater,
ii) at least two tree heights in width, and
iii) is designed to manage the area as an even-aged stand.

The clearcut system is the most straightforward and easiest system to use and has been applied around the world. While it has been successful for pure timber management, especially for valuable shade-intolerant species, concern over aesthetics, habitat impacts, and watershed impacts have prompted interest in alternate systems.

Clearcuts can create habitat for a variety of wildlife not found in mature forests particularly where snags or live trees with cavities and perches are left throughout. Raspberries, pin cherry, aspen, and white birch often sprout soon after cutting, providing valuable sources of berries and seeds (mast), browse, and cover for many species of wildlife.

The maximum clearcut size in New Brunswick is 100 hectares although the average is much smaller at about 35 hectares.

6.1.2 Patch cut

The patch cut system involves removal of all the trees, from an area less than one hectare in size. Each patch cut is managed as a distinct even-aged unit. If an area has several patch cuts, each opening is still managed as a distinct opening. Regeneration is obtained either by artificial or natural regeneration, or a combination of the two.

6.1.3 Seed tree cut

In a seed tree system, the entire cutting unit is managed as it is with clearcut systems except that, for a designated time, harvesting excludes those trees selected for the purpose of supplying seed. Trees are generally left just to supply seed for the next crop; therefore, the best trees should be selected to try to encourage desirable genetic traits to meet specified management objectives.

In a classic seed tree system natural regeneration is used, although the seed trees may not be relied upon entirely and some planting may occur beneath seed trees, often at reduced stocking levels. It is useful to conduct a stocking survey after three years and use fill planting to fill in any gaps in stocking. Usually, the seed trees are removed in a “removal cut” once regeneration is established, although in practice this is not always the case.

Figure 16. Seed tree cut where yellow birch trees were retained to regenerate the site. The ground was purposefully disturbed (scarified) during extraction to create a suitable seedbed to encourage regeneration. (Photo credit: Natural Resources Canada)

6.1.4 Coppice system

The coppice system is defined as an even-aged silvicultural system for which the main regeneration method is vegetative sprouting of either suckers (from the existing root systems of cut trees) or shoots (from cut stumps). This system is usually limited to broadleaved (hardwood) species management.

A good example of a coppice stand originating from sprouting in New Brunswick is trembling aspen regeneration following the harvest of a stand with a trembling aspen component. Trembling aspen roots do not die after the tree is cut but will produce hundreds if not thousands of root sprouts that will quickly occupy the site. As sprouts do not have to develop their own root system, they grow very rapidly often reaching 1–2 meters in height after one year.

Red maple will regenerate through vegetative reproduction from suckers originating from the stump after the tree is cut. As is the case with trembling aspen sprouts, maple suckers will grow very quickly. The number of suckers from a single stump can easily range from 20-30. The wood quality is poorer than trees grown directly from seed.

Although coppicing is an easy method to regenerate a harvested area (providing the area has tree species capable of regenerating from suckers and sprouts), the quality of the wood and the species that are regenerated are not always the preferred species of forest managers.

6.1.5 Shelterwood system

In a shelterwood system, the old stand is removed in a series of cuttings to release existing regeneration or to promote the establishment of a new even-aged stand under the shelter of the old one.

The primary intent of this system is to protect and shelter the developing regeneration. Generally, shelterwood systems aim at natural regeneration, although some planting may occur to diversify the species mix, bolster stocking, and introduce improved seed. The central theme to shelterwoods is that the overstorey leave-trees are left on site to protect the regenerating understorey until the understorey no longer requires the protection. At some point the overstorey starts to inhibit development of the understorey trees through crown expansion and shading. This depends on the density of overstorey trees, and the species being managed. The shelterwood trees are removed after the new trees no longer need their protection, so that the new tree can develop uninhibited.

Trees selected as leave-trees in shelterwood systems should be:

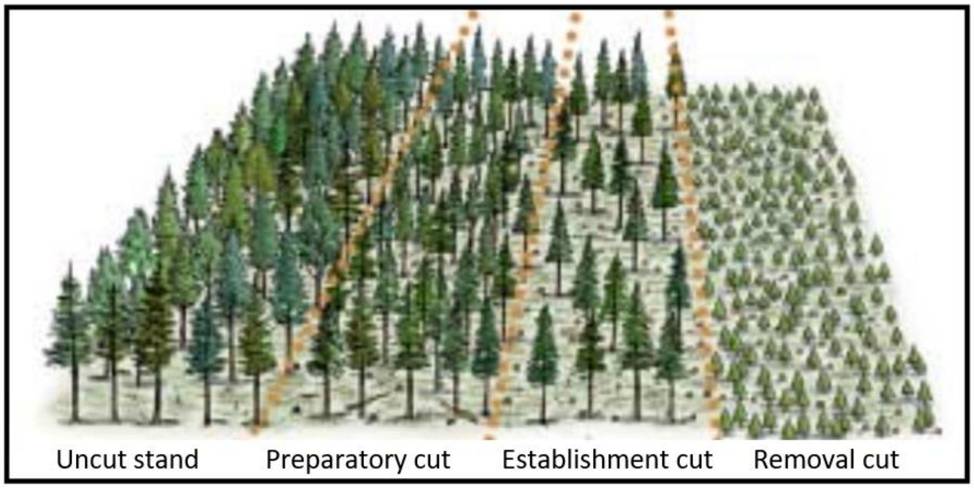
1. larger, dominant trees
2. intermediate or tolerant to shade
3. wind firm trees
4. desirable species
5. desirable physical characteristics

Shelterwood cuts are implemented by using a series of harvesting entries, each with specific objectives. These may or may not include the following depending on stand conditions:

1. <u>Preparatory cuts:</u> A preparatory cut is often the first entry in a stand intended for the shelterwood system. A preparatory cut is very similar to a commercial thinning, as the trees removed are usually the smaller, poorer quality trees in the stand. The objective of the preparatory cut is to begin to open the stand with the objective of improving the vigour of trees that will produce seeds and to make them more wind firm.

2. <u>Establishment cut (regeneration cut)</u> This cutting, which may be the first cutting in some stands, is intended to provide growing space for the regeneration to establish and to provide shelter for the young developing seedlings.

3 <u>Removal cut:</u> This is the final stage of shelterwood cutting and is carried out once the regeneration is well established. Great care must be taken so as not to damage the existing regeneration as these trees will be the future stand.



Variations to the shelterwood system include:

Uniform Shelterwood

In uniform shelterwood systems, treatments are applied uniformly throughout the stand: this is the standard type of shelterwood. The uniform system most often relies on a series of preparatory cuts (thinning) to prepare the stand for regeneration/establishment cutting, by encouraging crown expansion and promoting wind firmness and seed production.

Figure 17. Coupe progressive dans un peuplement de pins blancs (à gauche) et régénération de pins blancs (à droite). (Crédit de photo : Ressources naturelles Canada)

Group Shelterwood

Patches are opened in the stand such that the surrounding edges of uncut timber shelter the new regeneration. The group size will be increased by one or more cuts until the entire block has had the overstorey removed. This gradual removal of the original overstorey occurs relatively quickly in successive harvesting entries within a normal regeneration period for an even-aged stand (10–25 years). The final groups to be harvested may require artificial regeneration.

Strip Shelterwood

Initial harvesting occurs in the stand as uniformly spaced linear strips. In future harvesting entries, strips are added beside the initial strips, progressively into the wind, until the entire block is harvested within a normal even-aged regeneration period (10–25 years). Harvesting in each strip may occur gradually and include a preparatory, regeneration, and removal cut, following in sequence. Strips may be oriented to use the side shade from adjacent timber, maximize sunlight penetration, or allow for visual screening from the uncut timbered matrix.

6.2 Uneven-aged management system

Also known as the selection system or selection management, the uneven-aged management system removes mature timber either as single scattered individuals or in small groups at relatively short intervals, repeated indefinitely, where an uneven-aged stand is maintained. Regeneration should occur throughout the life of the stand with pulses following harvest entries.

Uneven-aged stands have an uneven and highly broken or irregular canopy (often with many gaps). This broken canopy allows for greater light penetration and encourages deeper crowns and greater vertical structure in a stand. Most stems occur in the smallest age/size class, as regeneration quickly fills the frequent canopy gaps. Because regeneration is initiated in small gaps, more shade-tolerant tree species are generally favoured.

Uneven-aged stands have at least three well-represented and well-defined age classes, differing in height, age, and diameter. Often these classes can be broadly defined as: regeneration (or regeneration and sapling), pole, and mature. (BC Ministry of Forests)

Uneven-aged management is generally considered to be more difficult than even-aged management since all age classes are mixed together and therefore can be difficult to isolate and quantify. However, uneven-aged management may be an objective for many reasons such as visuals, regeneration of shade-tolerant species, health, soil, habitat, and fire protection.

Under this management regime, trees are removed either as single scattered individuals or in small groups. To ensure that a proper age class distribution is maintained, uneven-aged management requires interventions in the stand every 15–20 years. Regeneration should occur throughout the life of the stand with pulses following harvest entries.

A good example of uneven-aged management is sugar maple stands managed to produce maple products. As only mature trees can be tapped for maple products, the owner must maintain trees of all sizes to ensure that as the older trees die, younger ones are there to replace them.

6.3 Reforestation

All provincial and territorial lands that are harvested for commercial timber in Canada must be regenerated either naturally or by planting or seeding. Each province and territory has its own regeneration standards and regulations, addressing such areas as species composition, density and stocking level, and the distribution of various forest types across the landscape.

The benefits of natural regeneration include the need for minimal human assistance and generally lower costs than for artificial regeneration. However, planting and seeding provides more control over what grows, so they are often used to ensure that provincial and territorial regeneration standards and forest management objectives are met. More than half of Canada's harvested areas are regenerated through planting and seeding activities.

In many ways, a forest plantation is like an agricultural crop. To ensure a successful plantation, the forest manager should:

Use good quality seed: New Brunswick has a long history of genetic tree improvement for reforestation. In 1976, the New Brunswick Tree Improvement Council was established to coordinate tree improvement efforts of government and industrial agencies and to facilitate the free exchange of genetic material and information. Early in the program, plus-trees—trees having superior, form, size, growth and insect and disease resistance—were selected and seed and cuttings was collected to establish seed orchards. Over the years, the best trees were selected, and pollen was collected and used to fertilize flowers of other selected trees. Seed from these crossed were planted to establish new orchards.

Today, seed used for growing tree seedlings in New Brunswick comes from second- and third-generation seed orchard trees. Seedlings grown from improved seed are faster growing and of higher quality than naturally grown seedlings.

Plant high quality seedlings: Most of the planting stock used in forestry comes from forest nurseries and are produced in large quantities. Seedlings used in forest plantations are small (especially when compared to ornamental trees or trees for urban planting).

Seedlings grown at the Kingsclear Forest Nursery, near Fredericton. (Photo credit: Natural Resources Canada)

Tree seedlings are usually grown inside nurseries under controlled conditions. Forest nurseries with greenhouse culture are best for areas with colder climates and short growing seasons. With controlled environmental conditions, it is possible to accelerate the growth of plants and, if required, have more than one crop each year. Today, almost all the planting stock used for reforestation is grown in containers.

Ensure good site preparation to provide good planting sites: Cutover areas often have considerable slash (branches, tree tops, and other harvest debris that pose obstacles to tree planters). Many forested areas also have a thick organic layer that can easily dry up during summer causing the seedling to dry out and die. For trees to survive, their roots must penetrate the mineral soil. To ensure good planting conditions and survival of planted seedlings, harvested areas usually undergo a site preparation treatment before planting.

Forestry worker planting containerized seedlings in a cutover. (Photo credit: Doug Pitt)

Many different types of equipment can be used to prepare an area for planting. Regardless of the equipment used, the objective is to create as many suitable planting spots as possible. Suitability for planting means easy access for planters and sufficient suitable microsites for seedling survival and growth. These microsites generally have adequate drainage, mineral soil and humus mixture, and minimal weed competition.

Chose the right species for the site: White and black spruce are the most commonly planted species in New Brunswick with Norway spruce, red spruce, jack pine, and white pine also planted but in lesser quantities. Hardwood species are not planted for reforestation in New Brunswick mainly because of the risk of browsing by deer and moose. Choosing the right species for the right site is critical, as each species is best adapted to the condition on the site.

Tend the planted trees so that they can grow free of competition: Planted trees are small and can be easily overtopped by competing vegetation such as grasses, ferns, shrubs and low-quality hardwood. To ensure their continued growth, a plantation tending is often needed. Plantation tending can be done chemically with an herbicide or mechanically using a brush saw.

Chemical release of planted trees using herbicide (left) and mechanical release using brush saw (right). (Photos credits: Doug Pitt (left) and NBDNR (right))

6.4 Pre-commercial thinning

Because the trees have not yet reached a size where they are commercially marketable for timber, this treatment is called pre-commercial thinning (PCT). Thinning can be carried out in stands of natural or planted trees that are of similar age and size.

Some of the best growing sites exhibit the densest thickets of trees. It is not unusual for some softwood thickets to contain over 30,000 trees per hectare. This silviculture treatment can be compared to thinning carrots in a garden and allows the best crop trees to obtain more sunlight, growing space, water, and nutrients.

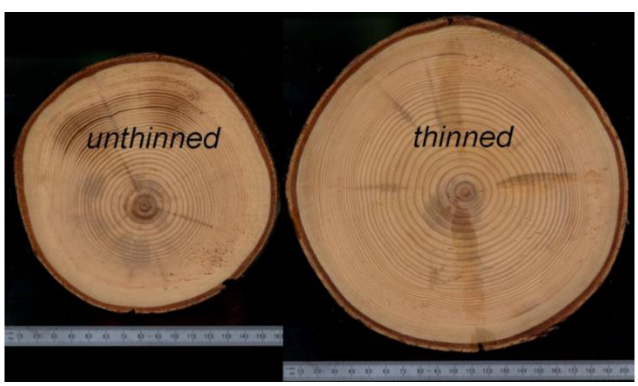
Silviculture worker doing pre-commercial thinning in young softwood stand.

Trees receive the most benefit from PCT when they are less than 20 years old and softwoods are 2–6 metres tall and hardwoods are 6–9 metres in height.

PCT is usually carried out with a clearing saw, also called a spacing saw or brush saw, which enables the user to avoid the back strain and danger associated with a chain saw. Softwood trees are usually spaced to 1.8 m to 2.4 m between trees (1,500 to 3,000 trees per hectare).

Choice of crop trees is ultimately up to the landowner but higher-value trees such as spruce are often chosen over balsam fir, tamarack, and poplar.

Shade tolerant hardwoods such as sugar maple, yellow birch, and white ash are commonly chosen over red maple, trembling aspen, and white birch. Hardwoods are usually spaced 2.4 m to 3.0 m between trees. Each PCT is unique, as tree size, species composition, density, and ground conditions differ on each site.



Increased diameter growth resulting from precommercial thinning.

6.5 Commercial thinning

The main difference between a commercial thinning and a pre-commercial thinning (PCT) is the size of the trees. A commercial thinning is generally done as trees are moving from a juvenile to a mature stage of growth whereas a PCT is done when the trees are still in the juvenile stage. Hardwood, softwood and mixed wood stands can all benefit from a commercial thinning.

Commercial thinning in a softwood stand.

Commercial thinning is usually carried out when the stand has reached a point where too many trees are competing for nutrients and light. When left to grow naturally, trees that have poor access to light and nutrients will slow in growth and will eventually die.

The objectives of a commercial thinning include:

- improve the growth of residual trees
- recover wood that would otherwise be lost to mortality
- improve stand composition
- improve the quality of the stand by removing dead, diseased, and deformed trees

While the need to carry out a PCT is based primarily on density, the criteria for commercial thinning is based on basal area and density. Different stocking charts are used depending on the species and site productivity.

6.6 Sustainable forest management

Sustainable forest management means ensuring that forests provide a broad range of goods and services over the long term. Forest managers plan for harvest levels that will not affect the long-term sustainability of the forest resource. To determine the yearly level of harvest allowed, governments estimate the wood supply, which is the maximum volume of wood that can be harvested sustainably. Both the estimated wood supply and the volume of wood harvested fluctuate in response to a wide range of ecological, social, and economic factors. Changes in wood supply are largely a result of adjustments in provincial forest management objectives. Comparing the amount of timber harvested to the estimated sustainable wood supply is one way to track forest management.

6.7 Annual allowable cut

The annual allowable cut (AAC) is the amount of wood (volume) that can be harvested each year without affecting the sustainability of the wood supply. The AAC is measured in cubic meters or cords (English system) of wood and is based on what the forest can grow.

The AAC can vary over time depending on what is happening to the forest. Certain factors or activities can increase the AAC while others may cause a reduction. Following are examples of how AAC can increase or decrease over time.

- Better forest inventory data (can increase or decrease AAC)
- Area available for harvest (can increase or decrease AAC)
- Insects and diseases (reduction in AAC)
- Forest fires (reduction in AAC)
- Silviculture (increase in AAC)
- Age class structure of forest (can increase or decrease AAC)

In New Brunswick, about 1.3% of the forest is harvested every year.

6.8 Stumpage

Stumpage is the price paid to the landowner or government for the right to cut trees in each location. To determine stumpage value, the area to be harvested is assessed and appraised through processes aimed at finding the volume of timber it contains.

Stumpage can be paid by cubic meter, weight, or area harvested (hectare). The amount paid is influenced by the type and quality of the wood, market conditions, accessibility (roads, proximity to the mill) and many other factors.

6.9 Forest products

Forests provide many products and services that we use daily. Most of the products we use have undergone some process that increase their value and make them usable. There are four broad classes of forest products:

1. Primary forest products are the raw materials extracted directly from the forest.
2. Secondary forest products include all products produced from primary products.
3. Non-timber forest products (NTFPs) which as the name suggest are products other than timber that are produced from the forest.
4. Innovative forest products are new uses for wood and its constituents that will replace products made from fossil fuels (plastics) and may replace steel and concrete in construction.

6.9.1 Primary forest products

Primary forest products are commercially valuable raw materials that are cut or harvested from the forest. These products come directly from the forest and that have not been altered or manufactured into something else. The most common primary forest products are sawlogs, studwood, pulpwood and biomass. These products are typically characterized based on their length, species, and top size.

Sawlogs: Some common species used as sawlog material include spruce, balsam fir, pine, eastern hemlock, and a variety of hardwood species such as sugar maple, red maple, yellow birch, and red oak. Sawlogs provide the greatest commercial value from trees. Unfortunately, only about 40% of the wood from sawlogs produces lumber. The remaining slabs of wood, bark, and sawdust is made into pulp, biomass, or other wood products. Sawlogs, especially quality hardwood sawlogs are high value products. Unfortunately, many hardwood sawlogs have defects that greatly reduce their value.

Studwood: Spruce, pine, and fir are usually used for producing studwood. Studwood is framing material used in housing and other construction. A typical “stud” is a piece of lumber measuring 2 inches by 4 inches and 8 feet long (no metric equivalent). These are commonly referred to as 2 x 4s.

Pulpwood Both hardwood and softwood species are used to make pulp. Temperate softwood species such as spruce and fir have long fibres that provide strength to paper and tissue products. The fibre length of hardwood species is shorter which gives these products a softer feel. Hardwood pulp can also be made into rayon used to make clothing.

Biomass: Forest biomass includes all parts of the tree, not only the trunk but also the bark, the branches, the needles or leaves, and even the roots. Biomass can be converted into solid, liquid, or gaseous biofuels that can then be burned for energy or used as fuel substitutes for transportation or industrial processes.

6.9.2 Secondary forest products

Primary forest products (raw materials) can be transformed into many different types of products that we use very day. The most common products are lumber from sawlogs and studwood. These primary forest products can be further transformed into secondary forest products such as flooring, furniture, mouldings, cabinets, pallets, boxes, crates, pulp, etc.

Paper is what most people think of when referring to products made from pulp. However, wood pulp is also used to make many items we use every day such as tissues, diapers, napkins, cardboard, and clothing to name but a few.

Various biofuels such wood chips, wood pellets and ethanol can be produced from forest biomass.

Research is discovering new uses for wood and its constituents. These innovative forest products will replace products made from fossil fuels (plastics) and may also replace steel and concrete in construction.

6.9.3 Non-timber forest products

The economic wealth of Canada's forests has long been measured in terms of the trees used to make conventional forest products, notably softwood lumber, newsprint and wood pulp.

In fact, numerous forest-derived resources make a significant contribution to many rural communities and households across Canada through sales revenue and seasonal employment.

Non-timber forest products (NTFPs) refer to products of biological origin other than timber, derived from forests. The range of NTFPs is very diverse and includes those that are:

- Gathered from the wild, in either timber-productive or non-timber-productive forests and lands (e.g., mushrooms, blueberries, fiddleheads, etc.)
- Produced in forests under varying levels of management intensity (e.g., maple syrup, Christmas trees)
- Produced in agroforestry systems (e.g., forest species such as wild ginseng planted as field crops)

Types of non-timber forest products (NTFPs)

- *Forest-based foods* – These include maple syrup, wild blueberries, wild mushrooms, and native understorey plants such as wild ginseng and fiddleheads. By-products of the forest industry can also be converted into prepared foods (e.g., lignin, a natural constituent of wood is used to make artificial vanilla).
- *Ornamental products from the forest* – These include horticultural species bred from wild species (such as cedars and maples) and decorative or artistic products such as Christmas trees and wreaths, fresh or dried floral greenery (e.g., salal), and specialty wood products and carvings.
- *Forest plant extracts used to make pharmaceuticals and personal care products* – These include paclitaxel (commonly known by the trade name Taxol®), which is most often extracted from yews like the Canada yew (ground hemlock). Taxol is widely used as a chemotherapy agent. Other forest plant extracts, particularly conifer essential oils, are used in a wide range of creams and other personal care products.

Value of NTFPs to Canada's economy

- Maple products represent a $354 million dollar industry in Canada. In 2009, the country produced over 41 million litres of maple products, including maple syrup. Canada produces 85% of the world's maple syrup.
- More than 1.8 million Christmas trees were sold in Canada's domestic and export markets in 2009. This seasonal industry is worth about $39 million annually.
- Canada is the world's largest producer of wild blueberries. It exported $207 million of fresh and frozen berries in 2014. Most wild blueberries are produced commercially in Québec and the Atlantic provinces as field crops.

6.9.4 Innovative forest products

Research is discovering new uses for wood and its constituents that will replace products made from fossil fuels (plastics). Some products may also replace steel and concrete in construction. The sky is NOT the limit when it comes to the potential products made from wood fibre. However, there are many surprising products that are now being produced, as well as some that are in the development stage.

1. THE COSMETICS INDUSTRY: The iridescent properties of wood fibre at the nano-level have vast potential in products such as lipstick and nail polish. Wood cellulose can also make cosmetic creams smoother and more luxurious. Sugars derived from wood can be used in a host of cosmetic products.

2. 3D PRINTING: Wood fibre has the potential to play a major role in the largest manufacturing revolution this century providing substrate for 3D printers from lignin, an affordable and renewable by-product of pulp mills.

3. THE ENERGY INDUSTRY: Many forest companies have become energy self-sufficient, thus removing the need for fossil fuels, by using pulping by-products and residues such as bark, shavings, and sawdust to produce greener electricity. Many mills are selling their excess energy to the grid.

4. THE GREEN CHEMICALS INDUSTRY: Bio-methanol produced as a by-product at traditional pulp mills can be used in windshield wiper fluid, plastics, glues, and fabrics or be blended with gasoline to fuel cars. This is just one example of the almost endless opportunities for bio-based chemicals from wood.

5. GREENING OTHER INDUSTRIES: Wood-based chemicals can be developed to help the oil and mining sectors remediate tailing ponds and landfills. For example, cellulose nanocrystals can be added to drilling fluids to minimize loss in geological pores.

6. COOL COMPOSITES: Cellulose products can be used as a substitute for glass fibres in reinforced plastics, for example for eyeglass frames. Research is examining making carbon fibre from lignin that could be used in high-end sporting equipment such as bicycles, golf clubs and tennis racquets. Sugar streams generated from wood can be used in a range of bio-plastics for example medical applications such as bone implants.

7.0 FOREST MEASUREMENTS

There are a variety of measurements and information that forest managers use to help them decide how forests should be managed. Although some information can now be obtained remotely, through LiDAR and other remote sensing technologies, foresters still need to verify this information by doing on site measurements and sampling.

Some basic forest measurements include age, height, diameter, basal area, density, stocking, and volume. Some of these can be obtained directly through measurement (age, height, diameter, density, basal area) while others must be calculated or determined from graphs or charts (volume, stocking).

The most basic unit in forest management is the stand. A stand is a community of trees possessing sufficient uniformity in composition, height, maturity, and health that allows them to be grouped together. A stand can measure anywhere from 0.5 hectare to hundreds of hectares in size. Measuring all the trees in a stand is not practical and therefore sampling is used to determine the characteristics of the stand.

7.1 Working with aerial photography

Aerial photographs are a valuable tool that has been used for decades to assist foresters in managing their woodland resources. For this discussion, an aerial photograph is a photograph taken from above the ground, usually by a plane. An aerial view of the landscape provides a much clearer image of what the landscape contains. This is extremely useful to foresters who need to understand what is on the landscape and what landscape features need to be considered when planning their activities.

The identification of landscape features is both an art and a science. A good photo interpreter can identify buildings, rivers, lakes, wetlands, power lines, and roads; distinguish between hardwood and softwood stands and measure heights, distances, and areas.

A single photograph provides the user with a two-dimensional view of an object. It is not possible to see depth (i.e. three dimensions) using a single photo. In order to see in 3D an object must be viewed from two different angles. Close one eye and look at an object—that object is seen in two dimensions as it is only viewed from a single point of reference. If you open your other eye the object can now be seen in 3D because the object is now viewed from two different points of reference.

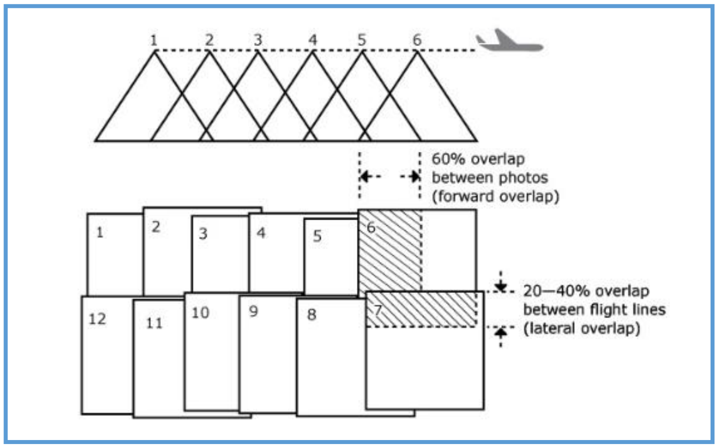
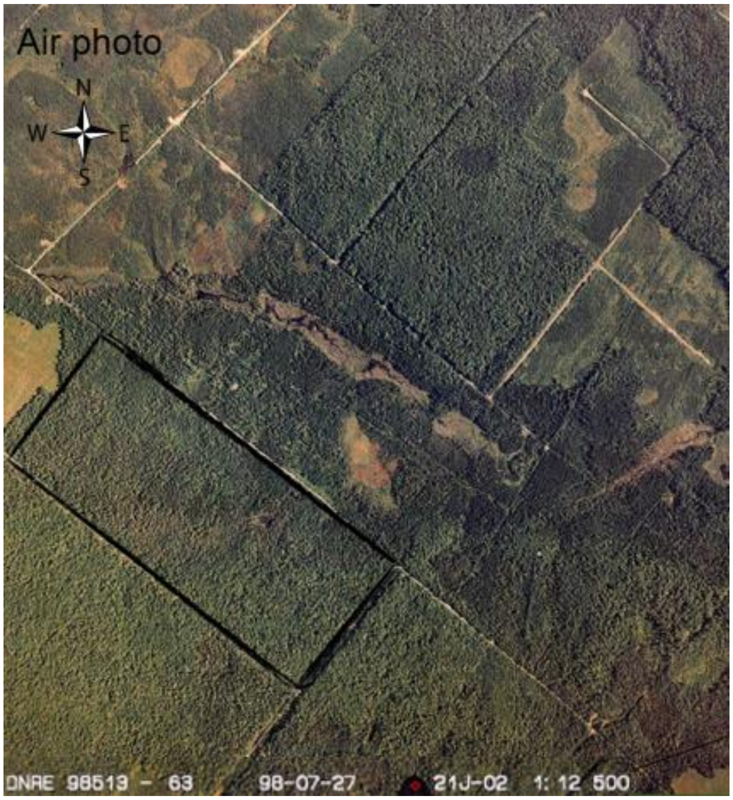


Figure 17. Flight lines are flown so that overlap occurs along flight lines (20–40%) and between photos along a flight line (~ 60%). This overlap makes seeing in 3D possible when using a stereoscope. (Natural Resources Canada)

To view aerial photos in 3D, two photos are needed that show the same object from different perspectives. The image on the right shows the overlap that allows photo interpretation in 3D to take place. A stereoscope is the instrument used to “bring together” the two images and allow the viewer to see in 3D.

Much information can be obtained from an air photo without the use of a stereoscope.



On this photo, you should be able to identify the following:

Roads

Watercourses

Clearcuts

Hardwood (lighter colour)

Softwood (darker colour)

Beaver dams

Wetlands

When looking at a map or air photo north is always “up” unless otherwise indicated. This means when reading text on a map the top of the map will be north. Below is an explanation of the text located at the bottom of the above photo.

DNRE	Department of Natural Resources and Energy
98519 – 63	Flight line and photo number
98-07-27	Date photo was taken
21J-02	Map reference
1:12,500	Scale of photo

The scale of the photo is very useful when determining distances. In this case 1:12,500 means that one unit on the map represents 12,500 units on the ground. For example:

1 cm on the photo is equal to 12,500 cm or 125 meters on the ground

The scale can be used to calculate actual distances and areas.

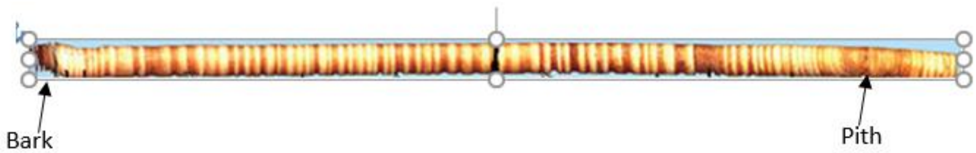
7.2 Tree measurements

7.2.1 Measuring the age of a tree

The age and growth history of a tree can help determine what management strategy to employ. As trees grow, they form rings made up of a band of light wood produced in the spring (earlywood) and a band of darker wood that forms later in the summer (latewood). This means the wood produced in one year can be measured by the width of one ring of light and dark wood. Counting the number of rings from the outer bark to the center of the tree (pith) tells you how old a tree is.

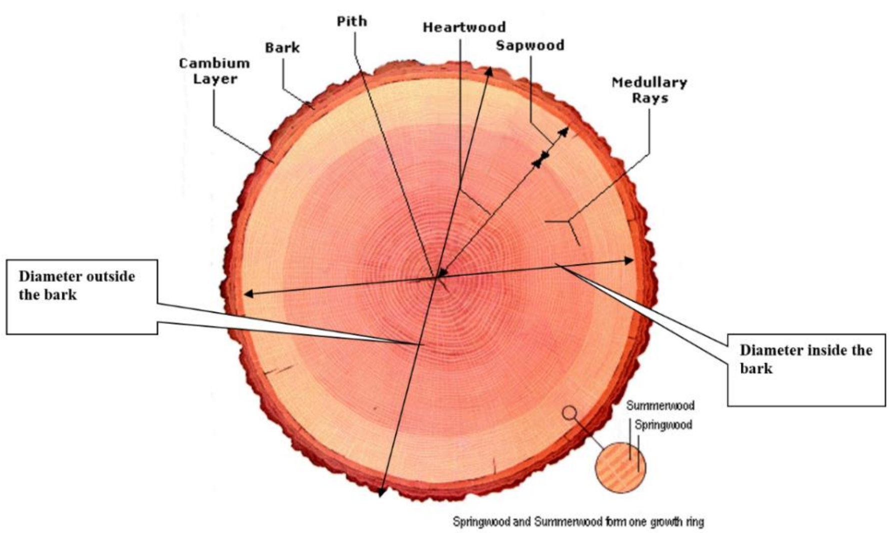
The size of a tree is not always representative of its age. A tree's age can easily be determined after a tree is cut by counting the number of growth rings on the stump.

An increment borer is a tool that drills a small hole in a tree. It is important to drill straight and far enough into the tree so that the bore reaches the center (pith) of the tree. A small core (below) can then be extracted, and the annual rings counted to determine the age of the tree.



7.2.2 Measuring tree diameter

A diameter is a straight line passing through the center of a circle and meeting at each end of the circumference. Diameter is important because it is one of the measures that can be measured directly and is used to compute basal area and volume.



Diameter at Breast Height (DBH) is the stem diameter of a tree **1.3** meters above the ground measured from the uphill side of the stem.

Why Measure at DBH?

1. provides a convenient point of measurement
2. provides a less fatiguing point of measurement
3. uniform point of measurement
4. accepted as a world standard
5. DBH is normally high enough above the ground to avoid erratic taper resulting from root and butt deformities
6. DBH is usually above the snow in the winter, but winter does present a challenge to accurately locate DBH

With the definition of DBH, it would seem the problem of where to measure diameters has been simply solved. However, the first time one heads to the field to measure tree diameters, it is likely that the technologist will run into some trees that are a problem to measure at DBH. Trees can be forked at DBH, below DBH and above DBH. Excessive branching can make it impossible to measure the diameter at DBH. Trees can be diseased or wounded at DBH causing a bulge. Therefore, to measure these trees there have been rules established to determine the correct place to measure DBH on trees with issues that if not accounted for would yield an abnormal diameter and therefore a volume that is incorrect (Figure 18).

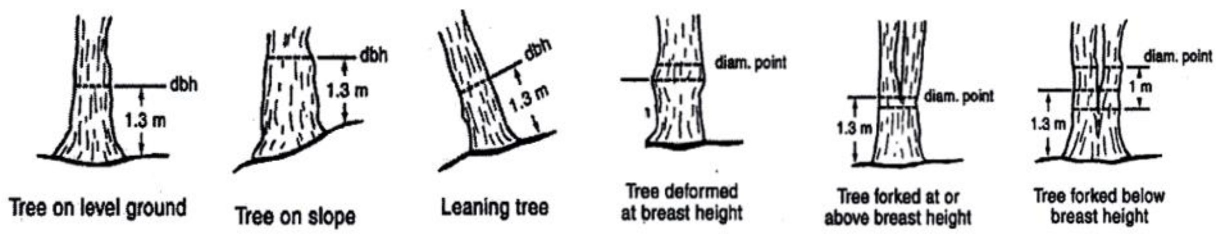
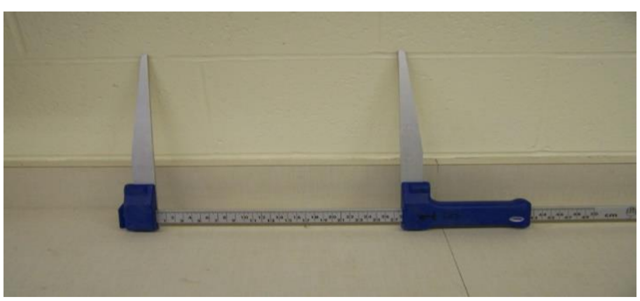


Figure 18. Determining the correct height and location to measure stem diameter for common tree stem characteristics found in the forest

Equipment

Instruments used for measuring diameter: Collectively these are called dendrometers.



Calipers

Diameter tapes

7.2.3 Measuring tree height using Suunto hypsometer

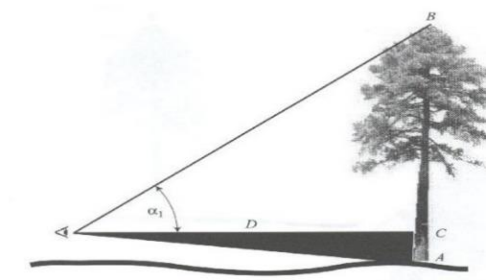
The height of a standing tree is the distance between the mean ground level to the top of the tree, measured along the axis of the tree. Instruments used for measuring height are called hypsometers. The Suunto is the most common hypsometer used today.

It is a handheld device that is housed in a corrosion-resistant aluminum body. A jewel-bearing assembly supports the scale, which is immersed in a damping liquid inside a sealed capsule. The liquid dampens undue scale movement.

The advantage of this instrument is that it is compact, accurate and relatively inexpensive. The major disadvantage is that the operator must line up the top of the target with one eye while reading the appropriate scale with the other.

How to Measure Tree Heights with a Hypsometer

1. Find a position, (at least one tree length) where the top and base of the tree are visible.
2. Measure (in meters) from the center of the tree to the location you want to take the reading.
3. The Suunto hypsometer we use for Envirothon has three scales: 20 scale on left; 15 scale in the middle; and a percent scale on the right.
4. If you stand at exactly 15 or 20 meters from the tree, you can read directly from the scale on the Suunto. If you are not at 15 or 20 meters, you will have to do some calculations to determine the height of the tree.
5. Take a reading at the top of the tree, lining up the crosshair to the tallest tip on the tree and reading the appropriate scale reading. This is usually a positive number.
6. Take a reading at the base of the tree using the same scale. Usually this is a negative number.
7. Use the following formula for determining tree height:



Tree Height = <u>Horizontal Distance x Net Reading</u>
Scale Used

Note: *If the horizontal distance is the same as the scale used, they cancel each other out in the formula, and therefore the net reading equals the tree height.*

Rule about signs with the hypsometer to determine Net Reading

- Like signs, you must subtract the two readings
- Unlike signs, you must add the two readings to get the net reading

Example:

If the tip reading is +16.5 and the base reading is -1.25, then the Net Reading is 16.5 + 1.25 = 17.25.

If the reading at the base was +1.25, then the net reading would be 16.5 - 1.25 = 15.25.

- When using the hypsometer, both eyes must be open; this is a necessity with the Suunto.
- The observer should try to position himself at about the same ground elevation as the base of the tree.
- Leaning trees should be measured at about right angles to the lean.

7.3 Stand measurements

7.3.1 Measuring basal area with a wedge prism

The wedge prism is a wedge-shaped piece of optically ground glass which deflects or displaces rays of light.

How to use a wedge prism

1. On flat ground, the prism is held between the forefinger and thumb, so that the bottom of the prism is parallel to the ground. This means the thick edge is on the side not the bottom or the top.

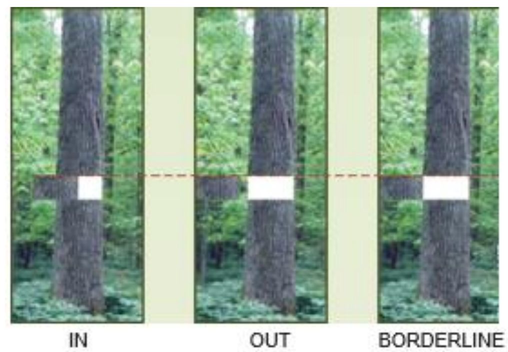
2. Prisms are held over the plot centre and trees are assessed at diameter breast height.

3. Looking through the prism (one-eye) a section of the tree will appear to be displaced away from the stem (see figure below).

4. If the section that is displaced is within the bole of the tree, the tree is IN the plot.

5. If the section displaced is completely outside the original tree, the tree is OUT.

6. If the section is displaced so that the side of the displaced section is in line with the bole of the tree, the tree is BORDERLINE. Every second borderline tree is counted.



7. By making a 360° sweep around the point all trees that qualify and half the trees that are borderline are counted.

8. On sloping ground, the prism is rotated through a vertical plane so that the angle between the imaginary horizontal plane and the bottom of the prism is equal to the angle of the slope of the ground.

9. Basal Area/hectare is calculated by multiplying the average count by the basal area factor of the prism.

Basal area of a single tree is the area of the cut stump of the tree if the tree was cut at DBH. It is determined mathematically using following formula. Basal area is expressed most often in m^2 but cm^2 may also be used.

$$\text{Area } m^2 = \frac{\pi R^2}{10000}$$

where R^2 = Radius of tree (cm)

10000 = Constant to change $\mathbf{cm^2}$ **to** $\mathbf{m^2}$

Example: The basal area of a 24 cm tree is equal to:

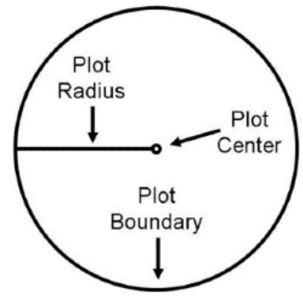
$$BA\ (m^2) = 3.14 \times 12^2 / 10000 = 0.0452\ m^2$$

Basal area per hectare is the total surface area occupied by trees on one hectare of forest, expressed in m^2

7.3.2 Stand density

Stand density is defined as the number of stems (or trees) per unit area (stems/hectare). As it is impractical to count all the trees in a stand, sampling is used. Circular plots are often used to determine density. The size of the sample plot depends on the number of stems to be counted. For example, the density of a young balsam fir thicket could be 50,000 stem/ha while the density of planted trees in a plantation could be 2000 planted trees/ha. Using the proper plot size is critical when sampling for density.

For example, a $5m^2$ sample plot would be appropriate to determine the number of stems in an area to be pre-commercially thinned. The 5 m^2 plots represents 1/2000 of a hectare, so to calculate the number of stems/ha, the average of stems counted in the sample plots would be multiplied by 2000. Another example would be to determine density of an area that had been planted or one that had been thinned. A 5 m^2 plot would not be practical because it would sample too few trees. In this case, a 40 m^2 or 50 m^2 plot would be more realistic.



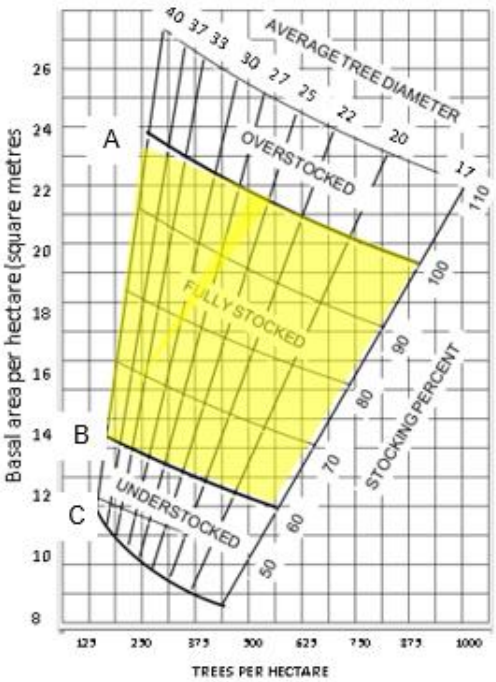
When sampling in the field, a cord cut to the proper length can be used to create a plot. The cord is fixed in place, and this becomes the plot centre. The cord is then moved in a circular fashion and all trees that are inside the plot boundary are counted. To determine the plot radius of a 40 m^2 plot use the formula for the area of a circle and solve for r.

$$\text{Area} = \pi r^2 \qquad 40\ m^2 = 3.14\ (r)^2 \qquad r = 3.57\ m$$

7.3.3 Stocking

Whereas density measures the number of trees per unit area, stocking is a measure of how fully occupied (stocked) a stand is. Stocking is used when the trees are bigger. Stocking charts use basal area and density are used to determine the stocking level.

Stocking charts, as the one seen below, tell the forest manager if the stand he is assessing is understocked, adequately stocked, or overstocked.



The **A-line** corresponds to the upper limit of a fully stocked stand. If stocking levels are above this line, the stand is overstocked and basal area should be reduced so that it falls in the fully stocked area of the chart (yellow section).

The **B-line** corresponds to the lower limit of fully stocked stand. If stocking levels are between the B-line and the A-line, the stand is growing as it should and does not require thinning at this time.

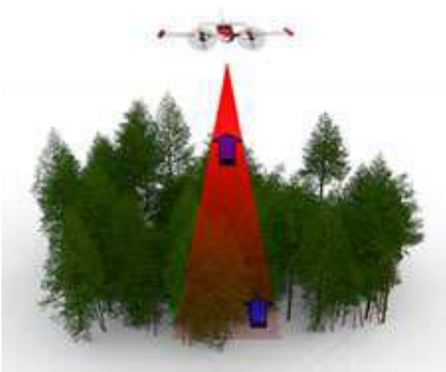
The **C-line** is an estimate of the lowest stocking that will grow to the B-line within ten years. The exact timing is dependent on site quality.

Stocking charts are used to help determine how much basal area to remove in commercial thinning or shelterwood cutting treatments.

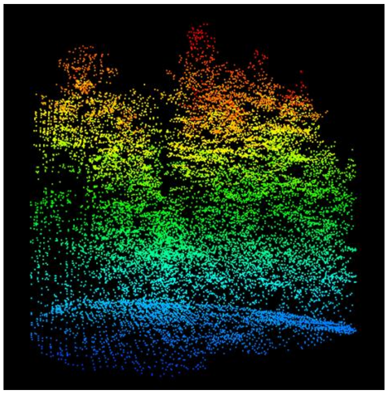
7.4 LiDAR

Forest inventory in Canada is undergoing a paradigm shift. Light Detection and Ranging, more commonly known as LiDAR is being used to add increased information to our existing inventories.

LiDAR units can be mounted on an airplane or helicopter or used from the ground and, when combined with GPS technology, create a spatially accurate representation of the forest. Laser beams are projected towards the targeted features at thousands of pulses per second and the returning signal from these pulses creates a 3-dimensional point cloud image of the vegetation, ground surface, or any other intercepted object. Lasers use short wavelengths that are very effective at reflecting off small objects and can therefore produce high-resolution images.



GPS + Laser



Point cloud

Figure 19. Aerial LiDAR measures the time it takes for a laser to strike an object and return to the source (Natural Resources Canada, 2015).

Although LiDAR has been around for several decades, its use in forest inventory is relatively recent. LiDAR has the potential to revolutionize many aspects of forest management in Canada.

The strength of LiDAR is that it directly and more precisely measures vertical structures on the landscape. The ability to accurately measure the height of the canopy, ground elevation, and the vertical structure of the forest provides a wealth of information relating to stand structure. An important advantage is that it has the ability to produce statistically-based predictions of the stand attributes that are critical to sound forest management.

8.0 FOREST HEALTH

8.1 Biodiversity

Biological diversity, or biodiversity, includes all the life on Earth and the natural patterns it forms. Biodiversity includes genetic, species, and ecosystem diversity. Abiotic components are also part of an ecosystem's biodiversity as they contribute to ecosystem functioning. Biodiversity drives many natural processes and functions that are required for the survival of humans. These processes include purification of air and water, recycling of nutrients, and fertilization of crops. Without these vital ecosystem services, humans would not be able to survive.

Trees play a crucial role in many ecosystems and are very important to animals as they offer habitat and food sources. Insects, birds, and mammals eat the leaves, flowers, fruit, bark, and twigs of many trees. Birds and other animals use trees for nesting areas. Many animals use trees as a shelter from harsh weather. Other plants have a symbiotic relationship with trees and require their presence for survival. Trees are also very valuable to humans. Trees offer us shade and create beautiful colours for us to enjoy in the fall. Trees provide us with many products such as wood to create furniture, houses, fuel, and materials such as sap and nuts for food and bark for medicines.

Biodiverse forest ecosystems are often healthier because they have higher **redundancy** and **resiliency**.

Redundancy occurs when more than one species performs the same or similar vital functions in an ecosystem. High redundancy is beneficial to ecosystems because, if one species is removed from the ecosystem, there will be another species to perform its function.

Resiliency is the ability to recover from, or to resist being affected by a disturbance. Biodiversity plays crucial roles in ecosystem resilience by ensuring ecosystems are capable of reorganizing after a disturbance. Resiliency increases when there is high redundancy within an ecosystem as species can replace each other in times of disturbance.

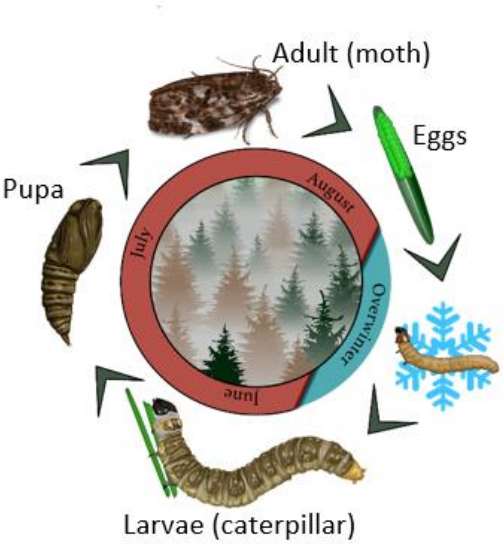
The main threats to forest biodiversity include habitat loss, fragmentation, degradation, invasive alien species, and climate change. Many human impacts are resulting in habitat loss, fragmentation, and the degradation of the landscape. The building of roads, urban sprawl, recreation, logging, and agriculture has an effect on the number of species in an area. This not only affects forest biodiversity but the biodiversity of all species living with and depending on the trees. With fragmentation, seeds are not able to spread and invasive species are more likely to expand into forest ecosystems and out compete native vegetation. Climate change is also a major threat to forest biodiversity. With temperature changes, trees may not be able to adapt quickly enough.

8.2 Native insects and diseases

Native insects and disease can cause severe impacts on forest ecosystems through defoliation and mortality. However, these ecosystem changes are not always detrimental as it can help to renew forests by removing older trees and allowing younger trees to thrive. Some insect species can cause outbreaks periodically and have large-scale impacts on healthy forests. An example of this is the spruce budworm, which has outbreak cycles every 30 to 40 years in the boreal forest. These outbreaks can be quite large, and repetitive years of defoliation can result in significant mortality. In addition, dead trees provide high quantities fuel sources that increase the risk of wildfires.

8.2.1 Spruce budworm

The spruce budworm is a native forest insect that inhabits the spruce-fir forests of northeastern North America. Spruce budworm completes its life cycle in a single year. After emerging from its pupa, the female moth mates and lays an average of 180 eggs on the needles of spruce and fir. The eggs hatch in about ten days and shortly after, the young larvae crawl into bark crevices, under bud scales, or other sheltered areas and overwinter in a small cocoon (hibernaculum). Sampling of overwintering larvae provides estimates of population levels for the following year.



Life cycle of spruce budworm

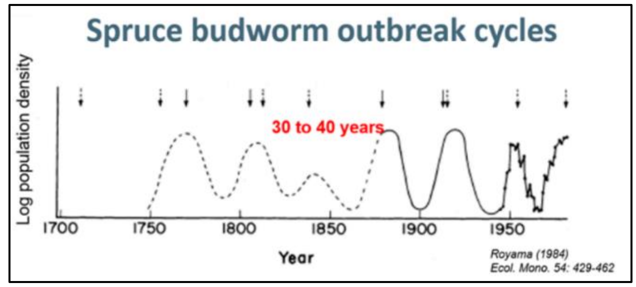
Damage (defoliation and tree mortality during outbreak)

Spruce budworms prefer to feed on the tender current-year shoots of balsam fir and spruce. The spruce budworm prefers balsam fir and during severe uncontrolled outbreaks, up to 85% of the mature balsam fir can be killed by spruce budworm. Mortality in spruce is also significant with up to 30–40% mortality of mature spruce occurring during severe uncontrolled outbreaks.

Spruce budworm damage starts in May. Defoliation begins at the top of the tree and quickly progresses to the edge of the crown from the top downwards. Current-year needles are partially or completely consumed and, if large numbers of larvae are present, previous-year needles may also be affected. Evidence of an infestation includes the destruction of buds, abnormal spreading of new shoots, defoliation of current-year shoots and the presence of large numbers of larvae suspended from strands of silk.

A single year of defoliation generally has little impact on the tree. However, it does cause weakening of the tree, making it more susceptible to attacks by other insects. Defoliation over several consecutive years causes tree growth loss. If defoliation continues over several years, tree mortality will occur. Balsam fir, the species most vulnerable to spruce budworm attacks, will begin to die after four consecutive years of severe defoliation.

Outbreaks of this insect generally occur every 30 to 40 years. During this cycle, populations of spruce budworm range from being vey low (endemic) to very high (epidemic). If left unmanaged, these outbreaks can result in millions of hectares of dead fir and spruce trees. During past epidemics, forest managers would wait until budworm numbers were high and the trees were at risk of dying before intervening. A foliage protection approach was used to protect the forest and insecticides were applied over large areas with the objective of keeping the trees alive until the epidemic cycle ended.



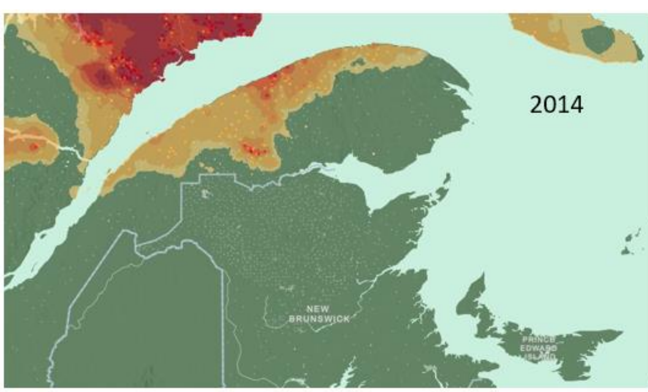
The last outbreak of spruce budworm in Atlantic Canada ended around 1990. Since then, natural controls (natural enemies and climatic factors) have kept spruce budworm numbers at almost undetectable levels.

In 2006, a new outbreak started in Québec and by 2014, had grown to 4.6 million hectares and was approaching the northern border of the province of New Brunswick.

In response to this threat of a new outbreak in Atlantic Canada, a group called the Healthy Forest Partnership (HFP) was formed. The HFP acquired funding to test a new approach to managing budworm populations. A research program called the early intervention strategy (EIS) for spruce budworm was undertaken to explore if it could be used to control hotspots at the leading edge of an outbreak with the objective of limiting further spread or reducing the magnitude of an outbreak in New Brunswick.

The EIS relies on intensive sampling to identify areas where populations of spruce budworm are beginning to rise and treating these areas with biological insecticides to keep numbers low. The approach used in Québec is the more traditional strategy of foliage protection. It differs from EIS in that populations of spruce budworm are allowed to rise and begin to cause defoliation before insecticides are applied.

By 2020, the outbreak in Quéec had grown to over 13 million hectares and defoliation by spruce budworm was occurring along the northern New Brunswick border. However, very little defoliation was occurring in New Brunswick.



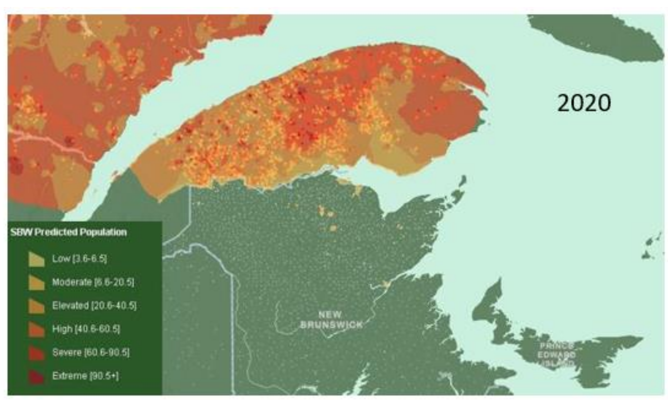


Figure 20. Spruce budworm defoliation in Québec and Atlantic Canada in 2014 at the beginning of the early intervention strategy and in 2020 after six years of early intervention against the spruce budworm in Atlantic Canada

The risk of a budworm outbreak in Atlantic Canada still exists as the outbreak in Québec continues. During spruce budworm outbreaks, massive dispersal events can occur which help spread the outbreak in new areas. The last massive moth dispersal event in New Brunswick was in 2016 but moths continue to move into the province on an annual basis. The dispersal event in 2016 was captured on Environment Canada weather radar (below).

Figure 21. Environment Canada weather radar showing mass dispersal event in July, 2016 (left) and photos of moths in Campbellton, New Brunswick following the mass dispersal event (centre and right)

Researchers remain cautiously optimistic that the EIS is a viable strategy to control budworm populations and potentially prevent large-scale outbreaks. The spruce budworm issue is extremely complex and the answer to the question of whether EIS will work will not be known until the outbreak in Québec has ended.

Since the beginning of the EIS in 2014, there has been no mortality of balsam fir or spruce in New Brunswick that can be attributed to the spruce budworm and only light defoliation levels have been reported in small pockets in northern New Brunswick. However, the risk of an outbreak remains high due to the continuing epidemic in Québec and from the risk of additional moth migration into Atlantic Canada.

8.2.2 Forest tent caterpillar

The forest tent caterpillar is native to North America and is the most widespread defoliator of deciduous trees. Its range extends from coast to coast.

Defoliation is caused by the caterpillar, which begin to feed on new leaves as soon as they appear in May. Given this insect's voracious appetite and gregarious behaviour throughout most of its development, its presence can be quickly detected. Older larvae devour entire leaves and, when the tree is completely defoliated, migrate in search of other sources of food. Larvae can also be observed in colonies on tree trunks sheltered from the sun's rays.

During massive invasions, trees can be completely defoliated over large areas. Even when severely defoliated, trees withstand infestations relatively well. Infestations generally last no more than three consecutive years. Defoliated trees will produce another crop of leaves during the season.

In the fall, the presence of egg bands, which resemble spongy, brownish masses, can be easily detected on small branches and twigs. In late June, the female deposits between 150 and 350 eggs in masses that encircle the twigs. The embryo develops over the course of the season and overwintering takes place as a fully developed embryo within the eggshell.

The insect has been known for many years and the first outbreak was recorded in 1791. Since then, the forest tent caterpillar has been reported at regular intervals in Canada.

Infestations are generally short, and parasitoids are very important in the natural control of populations. The most important parasitoid is the large flesh fly, which acts quickly after the start of an infestation, and can destroy up to 80% of the pupal population.

In recreational parks or on ornamental trees, it is recommended that egg bands be removed in the fall. At that time of year, they are more visible because the leaves have dropped. In the spring, colonies of young larvae at rest can be removed by hand. On small trees, a water jet can be used to dislodge larvae from the foliage.



Adult female moth (left); larvae (centre); egg band on twig (right). Photos Thérèse Arcand)

8.2.3 White pine weevil

Native to North America, the white pine weevil occurs throughout the range of white pine in eastern Canada. Damage is caused mainly by the larvae, which feed under the bark of the tree's terminal leader. Feeding punctures made by the adult weevils can also damage the leader.

The first symptom of weevil attack is resin oozing from small (0.5–1.0 mm) feeding punctures in the spring. The presence of the insect is easily detected by the drooping, wilted appearance of the current year's leader, which resembles a shepherd's crook. The leader is eventually killed. Symptoms are usually noticeable by late June.

Tree mortality due to the white pine weevil is rare, however. During outbreaks, the combined damage caused by adults and larvae results in reduced growth and usually in the total loss of the previous and current years' terminal shoots. In white pine with recurring annual damage, wood quality is affected, reducing merchantable timber volume by sometimes up to 60%.

The white pine weevil has only one generation per year, but the adults can live and continue laying eggs for several years. Adults overwinter in the forest litter, and, in early spring, they emerge when the temperature rises to 2–4°C. They crawl up the trunks of nearby host trees to the terminal shoot and begin to feed before mating. Weevils also disperse by flying on warm sunny days. The female lays her eggs in feeding cavities in the bark made with her rostrum. After the eggs hatch, in about 10 days, the larvae burrow into the bark, feeding on the cortex (inner bark). At the end of their feeding period, the larvae burrow in the pith or directly under the bark, forming pupal cells lined with strands of wood chips.

Adult white pine weevil (left); larvae in terminal shoot (centre); damage on white pine terminal shoot (right)

8.3 Invasive species

Invasive alien species are plants, mammals, fish, insects, other invertebrates, birds, reptiles, molluscs, microbes, and diseases that are introduced to an area and survive and reproduce, causing harm economically or environmentally within the new area of introduction. Invasive species can have devastating impacts on our native forest ecosystems because they can outcompete native species.

Invasive species are introduced through a variety of means from importing goods from other countries, ballast water in ships, within wood containers, and through recreation. Their management can be challenging because the impact of the new species is often unknown. Risk analysis and prevention is essential in protecting our environment, economy, and society from the impact of invasive species.

8.3.1 Beech bark disease

The disease results from the combined action of the beech scale insect and a pathogenic fungus. Most affected beech end up succumbing to the disease, either directly or as a result of being attacked by other pathogens.

In mid-summer, the female deposits her eggs (asexual reproduction) in the bark fissures. The larva hatches and stays in the same place or migrates to other cracks. In fall, the nymph becomes stationary again and secretes a woolly envelope. This woolly envelope makes the tree look like it is covered with snow. The scale insect overwinters in the bark of the tree. The fungal spores are disseminated by rain splash or by the wind and penetrate the tree through wounds created by the scale insect. The fungus first causes a depression in the bark of the affected region and cankerous blisters of various sizes also form. On severely affected trees, there are so many cankers that they end up merging.

American beech infected with beech bark disease (left) and not infected with disease (right). (Photos: Bernard Daigle)

8.3.2 Emerald ash borer

The emerald ash borer (EAB) is native to eastern Asia. It was first discovered in Canada and the United Sates in 2002.

While the EAB can fly up to several kilometres, the most significant factor contributing to its spread is the movement of firewood, nursery stock, trees, logs, lumber, wood with bark attached and wood or bark chips.

The EAB has killed millions of ash trees in Southwestern Ontario, Michigan and surrounding states, and poses a major economic and environmental threat to urban and forested areas in both countries. The EAB attacks and kills all species of ash (except mountain ash which is not a true ash).

The emerald ash borer typically has only one generation per year. Adult emergence starts with the month of June and ends with the end of July. A few days after mating, female lay eggs, one at the time, in bark crevices. One female lays between 60 and 90 eggs during its lifespan. Larvae dig s-shaped galleries in the phloem in order to feed. They hibernate in the bark and pupate in April or May. The life cycle of the EAB, north of its distibution area, is not known for the moment, but it could last two years.

Signs and symptoms include:

- yellowing of the foliage
- thinning crown
- evidence of adult beetle feeding on leaves
- long shoots growing from the trunk or roots
- vertical cracks in the trunk
- deformed bark (3–4 mm)
- small d-shaped emergence holes
- s-shaped larval tunnels under the bark filled with fine sawdust
- presence of woodpeckers in winter and woodpecker holes

Adult (left); larva (centre); galleries (right). Photos D. B. Lyons

8.3.3 Butternut canker

Butternut is a native tree species of central and eastern North America that is under serious threat from an introduced fungal disease. In Canada, butternut can be found in southern Québec and Ontario and in New Brunswick. The butternut populations in New Brunswick are the most genetically diverse and contain some of the last remaining uninfected butternut trees in North America.

The fungus infects butternut trees through buds, leaf scars, insect wounds, and other openings in the bark. It is believed that rain splashing can move the fungal spores from infected branches to other branches and that insects and birds may inadvertently carry the spores to the trees. A characteristic sign of infection in a butternut is cankers that leak a blackish fluid from cracks in the bark after a rainfall or in humid weather. These cankers coalesce and eventually girdle the main trunk, killing the tree. Controlling infected trees is not possible. This fungal disease is a fundamental threat to butternut and has caused this species to die out throughout much of its natural range.

In 2005, butternut was listed as Endangered by the *Species at Risk Act* (SARA) in Canada. A federal recovery strategy was developed for butternut in 2010 and notes that recovery will likely depend on finding canker-resistant trees, conserving genetic material, and instituting a program to restore viable populations.

The work currently being carried out in New Brunswick is a key component of this recovery strategy. The butternut project is using seeds to conserve butternut in the long term. Butternut seed cannot withstand much drying, and because of this, remains viable for only up to two or three years. Although whole seeds cannot be stored, research has shown that part of a butternut seed, the embryo, can be cryogenically preserved for many years in liquid nitrogen (-196°C). The National Tree Seed Centre at the Atlantic Forestry Centre in Fredericton, New Brunswick, has a cryogenic facility that can store close to 50,000 butternut samples.

Butternut canker has been found across the entire geographic range of butternut. It has killed up to 90 percent of the butternut population in some areas of the United States.



Butternut canker damage (lefty and centre); cluster of butternuts (right). Photos Tannis Beardmore.

8.3.4 Spongy moth

Formerly known as the gypsy moth, the spongy moth was introduced to the United States in 1869 and has become one of the most serious defoliators of hardwoods in North America.

Spongy moth damage is caused exclusively by the caterpillars, which feed on developing leaves in May. Newly hatched larvae are hairy and black and feed by chewing small holes in the surface of the leaves. Older larvae devour entire leaves. The body of the larvae are dark-coloured and hairy, with red and blue spots on the back. Full-grown larvae can be up to 65 mm long.

Another sign of spongy moths is the presence, in late July, of spongy egg masses covered with tan or buff-coloured hairs from the female’s abdomen on the trunks and branches of trees or in forest debris near defoliated trees.

During severe outbreaks, trees and shrubs are completely defoliated over large areas. Despite the trees’ ability to produce a new crop of leaves over the summer, the damage causes significant growth loss. Understorey shrubs and plants may also be affected.

Mature larvae feed at night and congregate in shady areas during the day, particularly in the litter near the trunks of affected trees. When the tree is completely defoliated, the larvae vacate the tree and migrate in groups in search of new sources of food.

Upon completion of their development, the larvae pupate, often in the same shady areas where they take refuge during the day. The adults emerge in July. The females, which are too heavy to fly, lay up to 1000 eggs per mass, often near the pupation site. The insect overwinters in the egg stage.

Adult female (top left); larva (bottom left); egg masses on tree trunk (right)

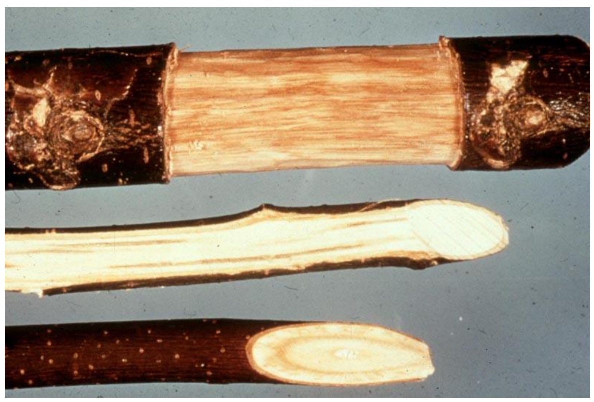
8.3.5 Dutch elm disease

Dutch elm disease was introduced into Canada around 1940.

The fungus causes a vascular wilt that results in browning of the foliage and kills infected trees. Because their sap supply is cut off and fungal toxins poison them, the affected parts of the tree wilt and eventually die; this process can take a few days or a few years.

The fungus develops in the sap-conducting tissues of elm trees, under the bark. The first symptoms of the disease generally appear between mid-June and mid-July. The leaves of affected branches wilt, curl up and dry out, while turning yellowish or brownish, but they usually remain on the tree. If the infection occurs later in the season, premature leaf drop usually follows the wilting. When an infected branch is cut, a ring-shaped brownish vascular discoloration can be seen. The exposed wood beneath the bark has numerous brown streaks.

The disease is transmitted by bark beetles. These insects dig galleries beneath the bark of weakened trees where they can reproduce. Once spring arrives, the bark beetles, which have in the meantime become covered by spores from the causal fungus, migrate toward healthy trees and begin feeding. The beetles thus contaminate new hosts and spread the disease. A new, more aggressive disease, *Ophiostoma novo-ulmi*, has resulted from natural mutation of the former disease. This disease has spread from the American Midwest and replaced the disease introduced in the 1940s.



Brown vascular staining caused by *Ophiostoma ulmi* in a white elm with Dutch elm disease

Infected elm tree (Photo: Pierre Desrochers)

8.3.6 Brown spruce longhorn beetle

In March 1999, the brown spruce longhorn beetle was found in dying red spruce trees in Point Pleasant Park, Halifax, Nova Scotia.

In its native range in Europe, the brown spruce longhorn beetle is recognized mainly as a secondary forest insect, attacking trees that have already been subjected to other types of insect attack or environmental stresses. During a population outbreak, beetles can attack living, healthy trees.

Symptoms of attacked trees include:

- streams of resin scattered along the trunk;
- holes in the bark about 4 mm across;
- networks of feeding tunnels just under the bark, up to 6 mm across;
- tunnels in the wood about 4 mm deep and 6 mm wide. These tunnels appear L-shaped when the wood is cut longitudinally.
- coarse sawdust may be found in and around tunnels or plugging the exit hole

The brown spruce longhorn beetle is now found throughout most of Nova Scotia and has recently been discovered in southeastern New Brunswick.

9.0 CLIMATE CHANGE AND CANADA'S FOREST

9.1 Canada's forests in a changing climate

The climate is changing and so are Canada's forests. Increased numbers of large fires, greater drought frequency and intensity, shifting patterns of disease and invasive insect outbreaks: all of these trends over the last five decades are impacting Canada's forests and have even resulted at times in loss of jobs and homes in some communities.

How the climate will continue changing is difficult to predict. However, because Canada is a northern country, the changes are expected to be greater than the global average. How Canada's forests will respond is also hard to know. However, scientists and other researchers are working to find answers that will reduce these uncertainties.

If global efforts to address climate change are successful in limiting the world's increase in temperature to 2°C, the increase in Canada is still forecast to average 4°C by 2100.

With the likelihood of new climate conditions, forests are expected to evolve, and in some areas become quite different from what they are now. Species composition, average age, geographic range, and growth rates are all likely to change over the coming decades. This makes adaptation by the forest sector—such as planting drought-tolerant species—more important than ever.

While Canada's forests will be affected by climate change, they may very well be part of the solution. Trees absorb carbon dioxide (CO2) from the atmosphere and store it in their trunks, roots, branches, and leaves. Increasing the area and growth of forests therefore reduces the amounts of greenhouse gases (GHG) in the atmosphere, helping to slow temperature rise. Using wood products and bioenergy also helps lessen the need for products made with processes that result in high GHG emissions and reduces the use of fossil fuels.

Canada's scientists have long been studying how changing climate conditions are affecting the country's forests. Milder, drier climatic conditions over the past 50 years are thought to be a major reason for longer fire seasons and the increase in the number of severe forest fires and the size of areas burned.


The State of Canada's Forests 2020

9.2 How forests could look in the future

Research on the biological, economic, and social implications of climate change for Canada's forests and forest industry is constantly improving our understanding of what the potential changes might be and how they could affect forest habitat and biodiversity, timber supply and communities.

Most areas in Canada are expected to experience at least a two-fold increase in annual area burned by forest fires and a 1.5-fold increase in the number of large fires by the end of the 21st century. This means that the average age of the country's forests is likely to decline in some areas, with increases in the number of young trees regenerating in burned out areas.

Forest growth rates and the distribution of species may also change. Climate conditions have already shifted, affecting the distribution of certain tree species in Canada. The rate of climate change is projected to be 10 to 100 times faster than the ability of tree species to migrate. This means that some tree species will benefit (for example, growing faster or spreading more widely), while others will become increasingly stressed, potentially dying out over time.

Such changes pose broader ecological consequences as well, affecting vegetation and wildlife, which would need to adapt or migrate under changing climate and forest habitat conditions.

Adapting to climate change means adjusting decisions and activities to take into account observed or expected changes in climate. In the forest sector, that means integrating climate change knowledge into sustainable forest management planning and practices to help maintain both ecosystem integrity and the flow of social, economic, and environmental benefits. Planting a greater diversity of tree species in a forest, for example, is one way of reducing the forest's vulnerability to future insect infestation or fire risks.

Adaptation measures are specific to a region and forest type and therefore vary widely. What best suits the local environmental and socio-economic needs in a region on the east coast might not offer the best solution on the west coast or in the northern boreal forest.

Adaptation will also be important to industry and communities as they adjust to the changing forests they rely on. Harvest levels, for instance, may need to be reduced as more frequent natural disturbances reduce the available timber supply. Forest companies will need to increase their efforts to find innovative ways to use more dead or low-quality wood salvaged from burned areas or areas invaded by insects or disease. Communities located in forested areas are already being encouraged to be “fire smart” by clearing trees and general forest brush (living and dead) from areas between buildings and forest.

9.3 Using Canada's forests to help mitigate climate change

At the climate change conference in Paris in December 2015, Canada joined the international community in aiming to achieve near-zero GHG emissions by 2050. Canada has committed to a 30% reduction in its emissions (below 2005 levels) by 2030. Further emission reductions will be needed after that in order to meet the international ambition of keeping the global temperature increase to below 2°C.

Given the current and projected impacts of climate change on Canada's forests, it may seem counterintuitive to think that forests can also be part of the climate change solution. However, the carbon-storing capacity of forests, together with the ability of wood products to replace fossil-fuel-intensive products, can contribute to keeping CO2 out of the atmosphere.

The ways in which forests are managed (tended, harvested, and regenerated) and harvested wood is used can therefore make important contributions to Canada's efforts to meet its climate change commitments. Among the mitigation actions being considered by various jurisdictions are the following:

<u>Increase the overall forest area</u>
Landowners could plant new forests on lands not currently part of the managed forest.

<u>Use sustainable forest management practices that reduce GHG emissions and store carbon</u>

- Forest managers could limit on-site burning of harvest waste (such as stumps, bark, and branches), using it for bioenergy instead;
- Make more complete use of the material harvested;
- Speed up reforestation after natural disturbances; and
- Increase growth rates in appropriate locations through intensive management.

<u>Use more wood in construction</u>
Builders could use more wood from sustainably managed forests in non-traditional construction applications in place of other materials whose manufacture, use, and disposal involve higher amounts of GHG emissions. The practicality and environmental benefits of using wood in construction are already being demonstrated in ever larger and taller wood buildings.

<u>Use more wood waste for energy and other bioproducts</u>
Industry and individuals could increase the use of waste wood for energy to replace fossil fuels or use bioproducts that replace similar products made from fossil fuels.

Some of the emission-reducing benefits from these activities would be immediate. Other benefits would take more time to achieve. For this reason, the sooner mitigation actions are undertaken, the more they will help Canada meet its GHG emission reduction target for 2030 and its longer-term move to a low-carbon economy.

9.4 Adapting to climate change in Canada's forests

As a biological resource, forests are on the front line in experiencing the effects of climate change. Trees are a renewable resource made of carbon and as such, they are part of the climate change solution. Some of the ways we can help our forests remain healthy and continue to provide essential services are:

Planting tree species with greater drought tolerance

Drought conditions reduce tree growth and productivity and can lead to tree mortality. Researchers are studying plant traits to identify tree species with greater drought tolerance and increased ability to reproduce following drought.

Fire-proofing neighbourhoods and communities

As fire activity in many regions increases, communities and homeowners are conducting hazard assessments and following FireSmart recommendations—for example, selecting fire-resistant plants with moist, supple leaves for landscaping and removing potential fuels such as dry grasses and dead branches from around homes.

Planting trees from a wider range of seed sources to maintain productivity

A tree planted today will mature in a warmer climate and may not grow as well in that regime. Foresters are therefore planting seedlings from a range of seed sources, favouring species from southern or lower-elevation populations—sources already adapted to warmer conditions.

Adjusting forest harvest schedules to minimize severe insect damage

As the incidence of severe insect infestations increases, foresters can adjust harvest schedules to remove vulnerable stands of trees ahead of pest attacks and harvest insect-damaged trees to maintain overall stand health.

Reducing damage to forests from wind storms

As temperatures warm, the early thaw and delayed freezing of soils provide less support for tree roots, making them more prone to uprooting during spring and fall wind storms in eastern Canada. Silviculture techniques such as varying the size and shape of harvest blocks and leaving patches can help reduce forest vulnerability to wind damage.

Finding ways to use the wood from dead and damaged trees

To offset the effects of damage to forests caused by insect and disease outbreaks, forest companies are salvage-logging and adjusting wood-processing techniques to create new products from dead and lower-quality trees.

9.5 Forests and Earth's carbon balance

The “carbon cycle” refers to the constant movement of carbon from the land and water through the atmosphere and living organisms. This cycle is fundamental to life on Earth.

Forests are a vital part of the carbon cycle, both storing and releasing this essential element in a dynamic process of growth, decay, disturbance, and renewal. At a global scale, forests help maintain Earth’s carbon balance.

Over the past four decades, forests have moderated climate change by absorbing about one-quarter of the carbon emitted by human activities such as the burning of fossil fuels and the changing of land uses. Carbon uptake by forests reduces the rate at which carbon accumulates in the atmosphere and thus reduces the rate at which climate change occurs.

How well forests will continue to remove the proportion of carbon now being emitted by human activities will affect the future rate of carbon increase in the atmosphere.

Earth’s carbon balance is calculated as the carbon emissions from human activities minus the carbon uptake by oceans and land systems. Since the industrial use of fossil fuels began, the net carbon balance has resulted in increases in the atmospheric CO2 concentration from 280 parts per million to over 390 parts per million.

As a major forest nation, Canada is working to understand how today’s changing climate will affect the global carbon balance, the health of the country’s ecosystems, and the flow of goods and services provided to Canadian society.

Canada also has international reporting obligations. Under the United Nations Framework Convention on Climate Change, Canada must monitor and report greenhouse gas (GHG) emissions and changes in the carbon stock in its managed forests. This means tracking changes that result from forest growth, decomposition, disturbances (fire and insects), and harvesting and land-use changes. Land-use changes include afforestation (that is, the creation of new forests where none exists) and deforestation (that is, the conversion of forests to non-forest land uses such as agriculture).

Forests can act as either carbon sources or carbon sinks.

- A forest is considered a *carbon source* if it releases more carbon than it absorbs. Forest carbon is released when trees burn or when they decay after dying (because of old age or of fire, insect attack, or other disturbance).
- A forest is considered a *carbon sink* if it absorbs more carbon from the atmosphere than it releases. Carbon is absorbed from the atmosphere through photosynthesis. It then becomes deposited in forest biomass (trunks, branches, roots, and leaves), in dead organic matter (litter and dead wood) and in soils. This process of carbon absorption and deposition is known as carbon sequestration.

The net balance of all these carbon exchanges determines whether a forest is a carbon source or sink. Yet, the carbon source/sink balance is as dynamic as it is complex.

For the past century, Canada's managed forests have been a significant carbon sink, steadily adding carbon to that already stored. In recent decades, however, the situation has reversed in some years. Canada’s forests have become carbon sources, releasing more carbon into the atmosphere than they are accumulating in any given year.

Several factors have contributed to this shift. The annual total area burned by wildland fires has increased substantially. Unprecedented insect outbreaks have occurred, and annual harvest rates have shifted in response to economic demand, increasing in the 1990s and decreasing sharply with the global economic recession.

The combination of these events and activities has resulted in Canada’s managed forest acting as a net carbon source in years when large areas are burned.

9.6 How climate change will affect the Acadian Forest

Researchers are using models to help determine how climate change will affect the trees of the Acadian Forest Region. To project the impacts of climate change on tree species, we need to know what changes in climate are likely to occur in the future. The United Nations Intergovernmental Panel on Climate Change (IPCC) has adopted four climate change scenarios that describe possible climate futures to the year 2100. The climate scenarios are referred to as “representative concentration pathways” (RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5). They represent different radiative forcing (warming) narratives (i.e., story lines) that humanity may follow depending on our future dependence on fossil fuels and on the level of greenhouse gas emissions. Scientists use these climate scenarios to predict future impacts under different levels of greenhouse gas concentrations.

The results shown here are from a paper by Dr. Anthony Taylor who used RCP 2.6 and RCP 8.5 in his models to project what changes would likely occur to the Acadian Forest. It is important to note that Dr. Taylor’s results are consistent with other research conducted on the impacts of climate change on the trees of the Acadian Forest Region.

RCP 2.6 assumes that greenhouse gas emissions will peak sometime between 2010 and 2100 and then start to decline. This situation represents a mean annual temperature increase of about 3°C from current conditions in the Acadian Forest Region by mid-century, at which time it will start to decline. RCP 8.5 represents a “business as usual” scenario in which carbon dioxide levels continue to rise unchecked, and the mean annual temperature continues to rise to about 7°C above current conditions by the year 2100.

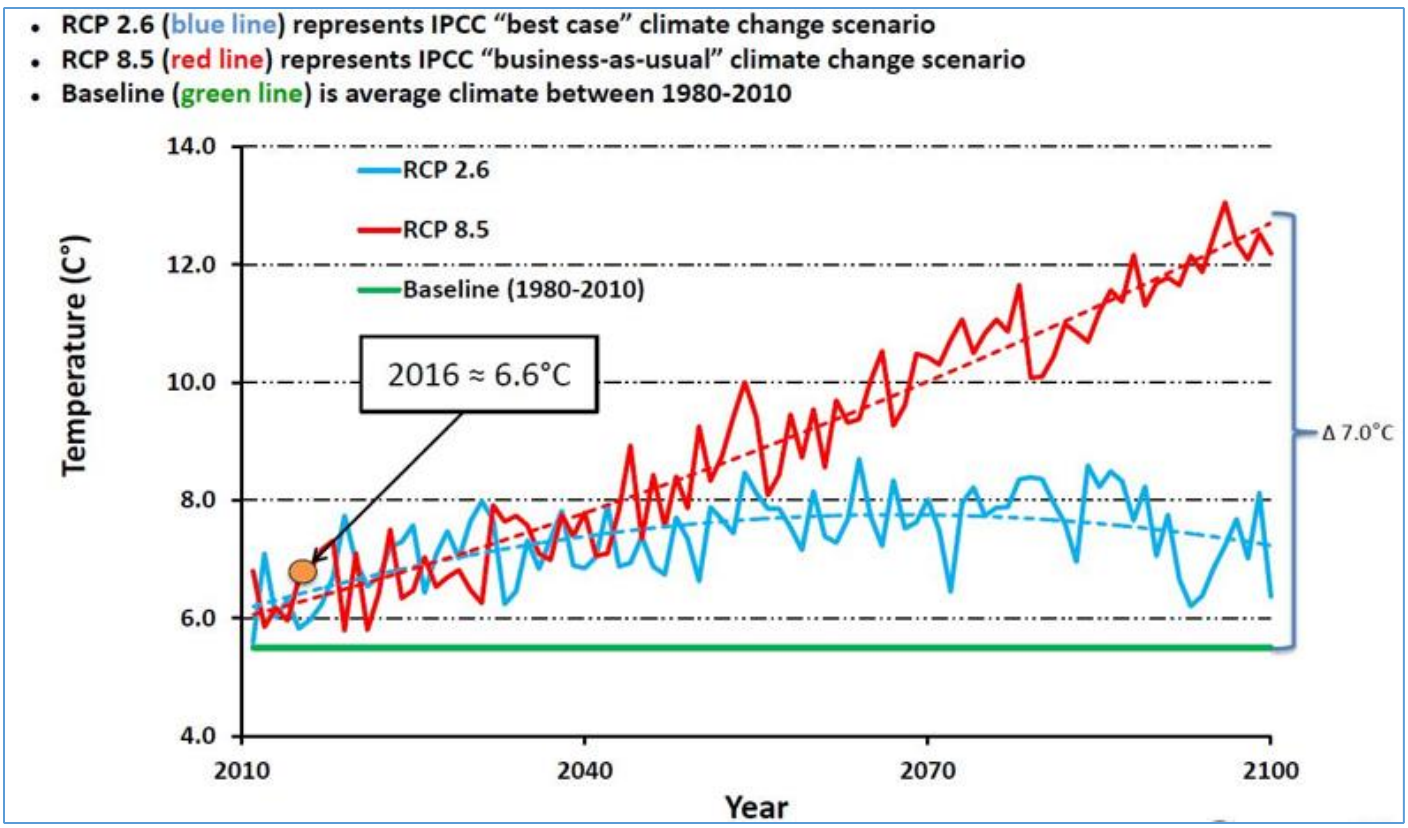


Figure 22. Climate change projections for the Acadian Forest under RCP 2.6 and RCP 8.5

Forest composition

The Acadian Forest Region is a mosaic of softwood, hardwood, and mixedwood forests. The Acadian Forest consists of tree species that are representative of the conifer-dominated boreal forest to the north and temperate deciduous forest to the south and west.

Boreal tree species such as balsam fir, black spruce, white spruce, white birch, and trembling aspen are at the southern limit of their ranges. Temperate species such as red maple, red oak, American beech, eastern hemlock, and eastern white pine are at their northern climatic limits.

Species that exist on the fringes of their home ranges are particularly susceptible to a changing environment. As the climate warms, tree species that characterize the temperate forest will find the conditions more favourable, while cold-adapted species of the boreal forest will find the conditions more challenging.

In the short term (years 2011 to 2040), little or no difference in forest composition is projected between the baseline (current climate) and RCPs 2.6 and 8.5. No discernible changes in forest composition were detected under RCP 2.6 over the long-term.

However, under RCP 8.5, the relative abundance of warm-adapted temperate tree species gradually begins to increase by mid-century while the cold-adapted boreal tree species (e.g., spruce and fir) decrease. By the end of the century, the abundance of spruce and fir is projected to decrease by 20 to 30% under RCP 8.5.

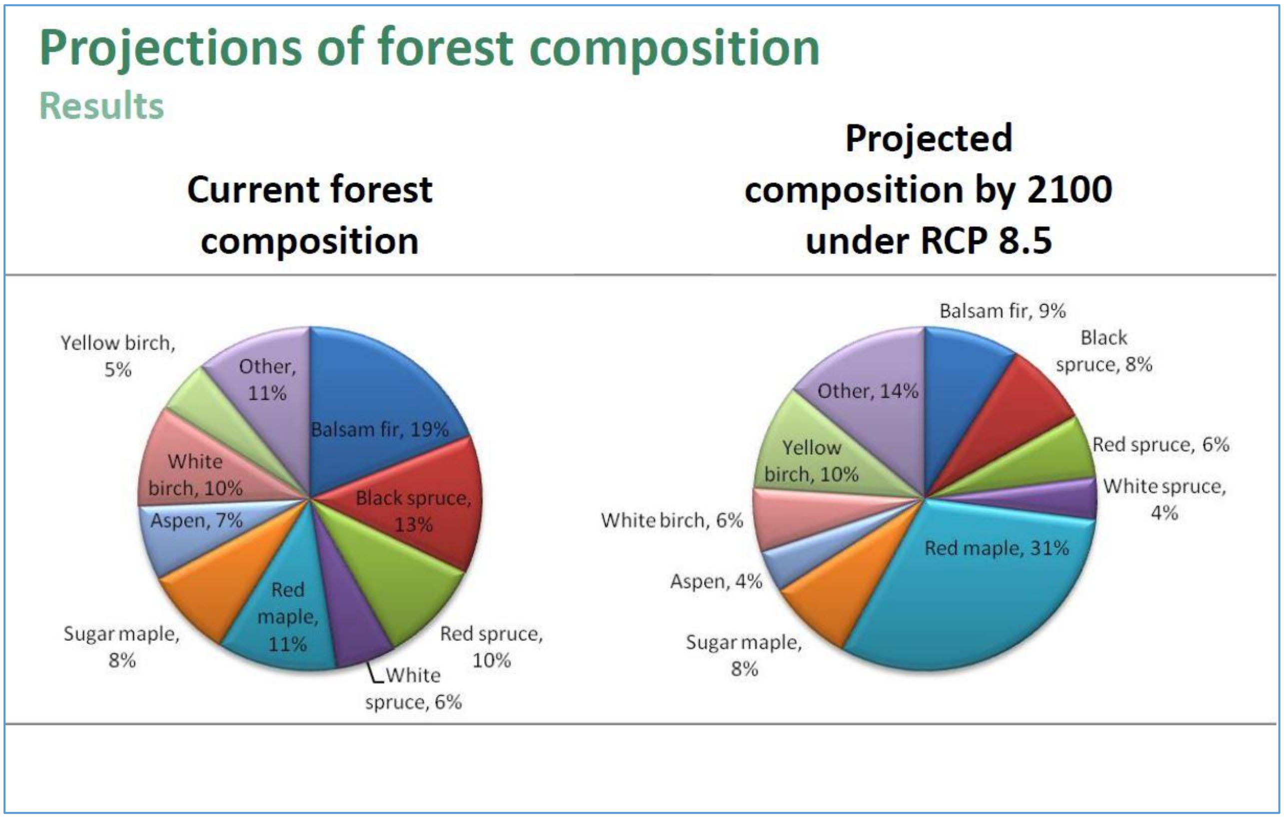


Figure 23. Comparison of current forest composition in the Acadian Forest and what the forest composition could look like under RCP 8.5

Forest growth

Similar to forest composition, in the short-term (2011 to 2040), little or no difference in forest growth is projected between the baseline and RCPs 2.6 and 8.5. In the long-term, growth rates under RCP 2.6 are slightly lower than baseline, showing a 6% decrease in growth by the year 2100. The greatest difference occurs under RCP 8.5, where a 42% reduction in growth is projected.

The main reason for the loss in productivity is a reduction in growth of the boreal species component of the Acadian Forest. This decrease in growth of boreal species is exacerbated by what Taylor and colleagues are calling a “blocking mechanism.”

What happens is maladapted boreal species are physically blocking the establishment of better-adapted temperate trees by continuing to occupy space. Because the climate is expected to change very rapidly under RCP 8.5, the forest is unable to adapt quickly enough, causing a lag effect. The effect is that there may be a temporary adjustment period for the warm-adapted temperate trees to gradually replace the boreal component.

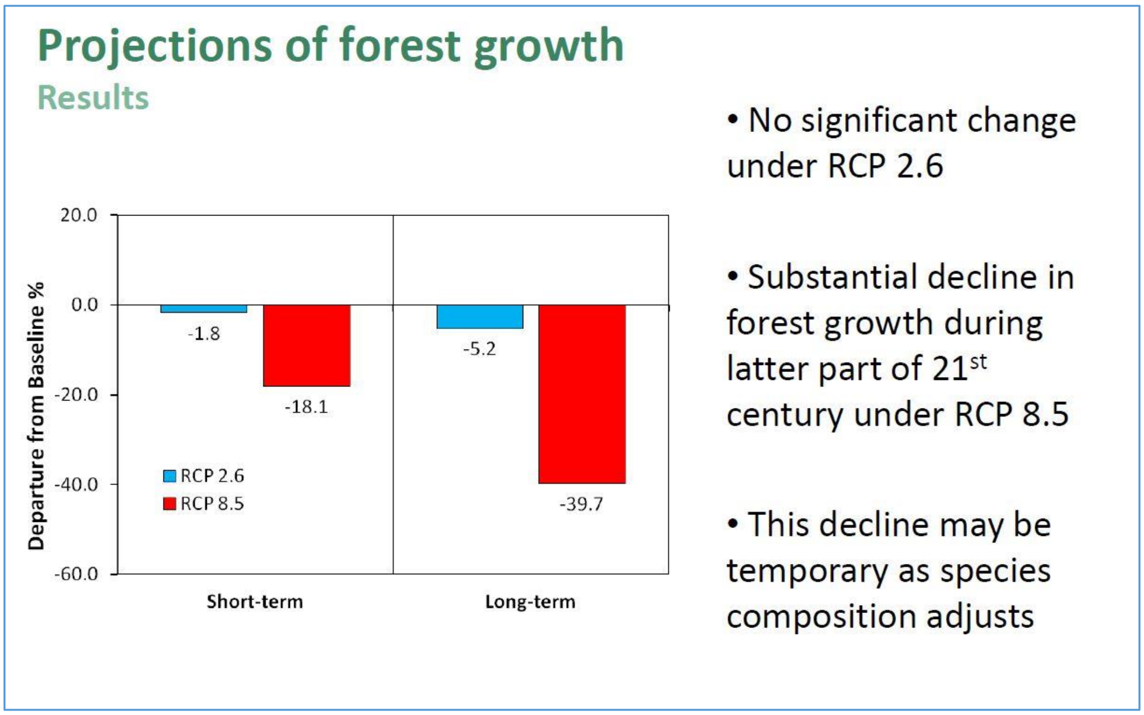


Figure 24. Projections of forest grown in the Acadian forest in the short and long-term under RCP 2.6 and RCP 8.5

Forest managers need to be aware of the effects that a warming climate may have on our forest, especially under a “business as usual” scenario represented by RCP 8.5. In this scenario, a reduction in valuable boreal species such as balsam fir, black spruce and red spruce will occur and will likely affect forestry in the region.

The forest industry in the Maritimes needs to be aware of these potential changes and consider how best to manage the forests as our climate changes.

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